8th International Laser Physics Workshop
Lphys'99

Budapest, July 2–6, 1999

Book of Abstracts

Edited by P. Domokos and T. Kiss

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1 Modern trends in laser physics

1.1 P. Adam, poster

Relations between input and output states of integrated optical systems

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Integrated optical systems, where several linear and nonlinear processes take place simultaneously, are important for different applications of laser light and generating nonclassical field states[1–5]. For a general two-mode process, when only processes with quadratical Hamiltonians are allowed, the relations between the input and the output creation and annihilation operators describing the field modes in the Heisenberg picture are

$$\begin{aligned} \hat{a} &= u\hat{a}_0 + v\hat{b}_0 + w\hat{a}_0^\dagger + z\hat{b}_0^\dagger \\ \hat{b} &= U\hat{b}_0 + V\hat{a}_0 + W\hat{b}_0^\dagger + Z\hat{a}_0^\dagger \end{aligned} \tag{1}$$

where the parameters can be determined knowing the specific form of the Hamiltonian. These equations describe a general optical four-port device. Important special processes are two-mode squeezing, linear coupling, frequency conversion, and examining only one of the modes, damping, amplification and squeezing. Eqs. (1) are valid for several important complex systems, as nonlinear couplers, phase conjugate resonators, and also for systems where basic nonlinear processes take place successively.

In this paper direct relations are derived between the input and the output Glauber R-functions, quasiprobability distribution functions, and the photon number representations of the density operator for systems described by Eqs. (1).

Using the derived general formulae the evolution of a coherent laser field and coherent state superpositions are studied. As a relevant example, nonlinear coupler with nondegenerate parametric amplification is analyzed in detail.

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1.2 N. Akozbek

Femtosecond Pulse Propagation in the Air: Variational Analysis

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We use a variational method to study the phenomena of intense femtosecond pulse propagation in the air. This method allows us to obtain a semi-analytical solution to the problem in which a wide range of parameter space can be studied. In addition it provides a simple physical interpertation, where the problem is reduced to an analogous mechanical problem of a particle moving in a potential well. We discuss different types of solutions under different initial conditions. The results recapture at least qualitatively some of the main experimental observations performed by the Laval group in Quebec, Canada.

1.3 A. V. Andreev

Interaction of atom with superstrong laser field

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The study of the light-atom interaction for a case of superstrong laser field is a problem of enhanced interest in the last time. The theory of the superstrong laser field interaction with atom is developed. The specific feature of the developed approach is that the solenoidal part of the driving field plays the role of the smallness parameter of the theory and the interaction with the potential part of the field is accounted accurately. The results of the research have shown that the approach based on the calculation of the multipole moments of atomic transitions ceases to be applicable when atom interacts with a superstrong laser field and should be substituted by the calculation of the atomic response which includes the sum of multipole moments of the all orders and depends on the instantaneous field amplitude. The comparison with the results of the perturbation theory using the interaction Hamiltonian as a smallness parameter is discussed. The developed theory shows the following specific features of the atom behaviour in the superstrong laser field. Firstly, the amplitude

of any eigenstate in superpositional state appeared under laser field action does not determine by the dipole moment of transition from the ground state. It is shown that the increase in the intensity of the driving field may result in the situation when the rate of excitation via dipole-forbidden transition exceeds that for allowed transition. Secondly, the interaction of atom with the superstrong laser field is characterised by the nonlinearities of the saturated type. The atomic response at a frequency of n-th harmonic is proportional to the n- th power of the driving field amplitude only in the week field. When the driving field amplitude exceeds the interatomic field the rate of ionisation does not depend on the finite state in the wide range of the harmonics number. In this case the integral atomic response depends only on the phases of different harmonics. Finally if an atom interacts with the spatially inhomogeneous field (laser beam, interference field, etc.) the gradient forces begin to play an important role. The transversal gradient forces become comparable with the longitudinal force acting along with the electric field vector when the beam width is about optical wavelength and the field amplitude is about interatomic. As a result the atomic response will be different from that when the driving field is a plane wave. This gives some additional opportunities for the emitted spectrum control.

1.4 V. V. Apollonov, poster

Gas-plasma and superlattice free-electron lasers exploiting a medium with periodically modulated refractive index.

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Amplification in FELs exploiting media with periodically modulated refractive indices is studied for a regime of a large modulation. The maximized gain, corresponding saturation fields, efficiency, electron energy and emittance are determined. Relation to other kinds of FEL is discussed. This research is partially supported by RFBR grant 97-02-17783.

The report aims to determine operation parameters of a compact free-electron laser (FEL) using Media with Periodically Modulated Refractive Index (MPMRI). These media are used for creation of compact sources of visible, UV, or soft X-ray radiation. The amplified electromagnetic wave can interact resonantly with an electron beam traversing the MPMRI via one of the diffracted partial plane waves (PPW) formed incide the medium. The MPMRI permeability was assumed to be STRONGLY modulated according a harmonics law. The maximized gain G and the corresponding optimum PPW index, the electron relativistic factor maximizing the gain, the saturation field of the amplified electromagnetic mode, and the efficiency of a FEL

based on a superlattice-like medium are presented. The calculations were performed for superlattice-like structure SLL-structure to be composed of KCl and amorphous quartz layers. Its transparency window is from 2.8 10^{15} 1/s till 10^{16} 1/s. The superlattice length L=0.5cm and modulation period was $l0 = 3.3\ 10^{-3}$ cm. The electric current density of the beam was j=5A/cm^2. It was found that the use of the large-modulation regime makes it possible to extend the operation frequency range of the FEL.

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1.5 S. N. Bagayev

High stable femtosecond Ti:Sa laser and its use in the metrology

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The stability and frequency spectrum of intermode beats of radiation from a Ti:Sa laser are investigated experimentally. The frequency stability of beats of adjacent modes of 1.27E-12 in 50 s is achieved. The possibility of measuring large frequency intervals (up to 10 THz) in the optical region of the spectrum is studied. The physical principles for the creation of an optical clock of a new type using highly stable femtosecond Ti:Sa laser are considered. First experimental results are presented.

1.6 V. Bagnato

The study of cold collisions involving different species

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One of the main motivation for the development of atomic traps was the novel collision process involved on it. Several studies both experimental and theoretical have been carried out for basically all the alkalis and a few other systems. An extence review on that has been recently published [1].

We have constructed a vapor cell MOT which has the capability of trapping two different species simultaneously. Any pair involving two of the following atoms Na, K, Rb and Cs can be trapped. The experimental system consists of a stainless steel chamber with four reservoirs containing the alkalis. These independent reservoirs allow us to pick the species to be investigated. Several parts on the chamber allow optical access for lasers and detectors. A combination of Dye, Ti : Sapphira and diode lasers provide all the necessary frequencies for trapping, repumper and probing.

A sequence of experiments involving two species has been performed. In a first class of experiments we have done measurement of trap loss rate for a mixture of atoms. The equation that determines the variation for the number of trapped atoms of the species A in the presence of B is given by :

$$\frac{dN_A}{dt} = L - \gamma N_A - \beta \int n_A^2 d^3r - \beta' \int n_A n_B d^3r$$

Where L is the loading rate, γ is the loss rate due to collisions with the hot background, β is the loss rate due to homonuclear collisions of species A, and β' is the loss rate due to heteronuclear cold collisions. The values of β' has been determined for Na/K[2], Na/Rb[3], K/Rb[4] and Rb/Cs.

Special techniques have been deviced to measure β' and its variation with light intensity. The behavior of β' (A/B) in contrast with β (A/A) has been investigated and the differences imply the presence of different mechanisms in the loss process. For β' it seems that collision involving Na (ground) - Rb (excited) are the dominant mechanism. Simillar analyses can be made for the others pairs.

For the low intensity regime, we have succeed in investigate the occurrence of hyperfine change collisions in alkali mixtures of Na/K[5].This study may have implications towards the production of double species Bose-Einstein Condensation.

Work supported by Fapesp and Programa Pronex.

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1.7 J. Bergou

Correlated emission laser (CEL) and the CEL gyro

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We give a brief overview of a particular laser scheme based on coherent pumping which leads to correlated spontaneous emission [1-3] and an eventual quenching or even squeezing of the quantum noise from the phase. In particular, we show that squeezing is compatible with inversion in lasers with coherent atomic initial conditions and a squeezed coherent state can be generated with a macroscopic coherent amplitude in the two-photon correlated emission laser [4]. The two most important CEL schemes involving coherent atomic initial conditions, viz. those of the quantum beat and holographic CEL, are then discussed in some detail. Lasers with coherent pumping can exhibit bistable or even multistable behavior and their stability is mentioned. We shall also briefly consider what happens when laser operation is built up from an initial squeezed vacuum [5].

Quantum noise quenching in the CEL is based on the following expression for the diffusion coefficient of the relative phase Θ between the two modes [1-2],

$$D(\Theta) = D_{ST}(1 - cos(\Theta)). \tag{2}$$

Here D_{ST} is just the Schawlow-Townes linewidth of an ordinary laser. It is the cosine term that is responsible for the correlation between the modes and it is easy to see that $D(\Theta = 0) = 0$. From the locking of the relative phase one can see that $\Theta = 0$ is a stable locking point. Thus, under stable steady state operating conditions the quenching of quantum noise from the relative phase takes place. A particularly nice geometric interpretation of the CEL effect has been given in [3]. A full nonlinear theory leads to virtually the same expression.

As an application we discuss the CEL gyro and show that the injection of a squeezed vacuum into a correlated emission ring laser gyroscope enhances the sensitivity of the device. In particular, we demonstrate that if the phase of the injected squeezed vacuum is chosen appropriately then the output is squeezed in the phase quadrature. This may lead to complete suppression of the shot noise in the signal. In addition, the effect of an apropriately designed extraction/amplification/reinjection feedback loop is shown to lead to further enhancement of the sensitivity [6].

This research was supported by the Office of Naval Research, and partly by the Hungarian Science Research Fund (OTKA, Grant Number: T 030671) and a grant from PSC-CUNY.

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1.8 J. Bergou

Generation of correlated photon–pairs in the resonance fluorescence of a bichromatically driven, trapped four–level atom

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Strongly correlated photons are the basic requirement for the generation of squeezing. For the production of EPR–pairs one needs, in addition, the presence of different polarization directions in the photon field in most cases. Both conditions can be met in the RF of a bichromatically driven four–level atom. The four–level atom has two twofold degenerate states where the degeneracy is with respect to the magnetic quantum number $m_j = \pm 1/2$ [1]. As a consequence of the internal structure of the four–level atom, different polarization directions are now possible in the RF and photons with different polarization directions are entangled. Thus, both two–photon emission and different polarizations can be realized in the case of a bichromatically driven four–level atom.

First, we study the polarization dependent resonance fluorescence (RF) spectra of a bichromatically driven four-level atom and show that very narrow spectral lines can occur in the incoherent part for polarization directions which are different from that of the driving field. More importantly, the degree of squeezing depends on the polarization direction and reaches a maximum of about 56% [2]. This should facilitate the observation of squeezing in the RF of a single atom.

Then, we show that the second–order correlation function exhibits anti–bunching [4] for zero time delay, independently of the interaction parameter ξ [3]. In addition, as in the case of a bichromatically driven two–level atom, resonant two–photon emission processes appear for certain values of ξ. Unlike in that case, however, these two–photon processes now exhibit a strong dependence on the polarization direction of the emitted photons. We found very strong super–bunching in two–photon emission for a pair of σ^+ and σ^- circularly polarized photons in the case of a z–polarized bichromatic driving field for small ξ, while two–photon emissions of a σ^+–σ^+ or a σ^-–σ^- photon–pair are not possible in this case. For an x–polarized bichromatic driving field there arise strong super–bunching effects between σ^+–σ^+ or σ^-–σ^- photon–pairs, due to the different polarization state of the driving field, while the σ^+–σ^- or σ^-–σ^+ photons are well separated in time.

A recent paper by Eichmann *et al.* [5] reported on interference experiments using the light scattered from two single $^{189}Hg^{+}$ ions in a linear trap. These ions have an internal structure identical to the 4–level atom we are considering in this paper. We showed that the system is appropriate for the realization of the quantum eraser [6]. A similar experimental setup would make the verification of the above results feasible. Many applications require appropriate superpositions of EPR– and/or Bell–states which, in the case of two trapped Hg ions, can be realized if we drive one of them with an x–polarized field and the other with a z–polarized field. Another important feature of this system is that we are in the steady–state regime of the atoms and, therefore, the generated two–photon states are free of decoherence as long as there are no other absorption or scattering processes.

This research was supported by the Office of Naval Research, by the Hungarian Science Research Fund (OTKA, Grant Number: T 030671) and by a grant from PSC-CUNY.

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1.9 C. M. Bowden

Quantum computation via laser pulse controlled electron-nuclear transferred hyperfine interactions

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Quantum logic is illustrated in the context of a generic scheme for laser pulse induced electronic excitation controlled transferred hyperfine interaction. For a quasi-pure state ensemble, several orders of magnitude speed-up of quantum logic evolution and initial state preparation and loading of registers is anticipated, as well as up to three orders of magnitude increase in readout signal compared to NMR counterpart schemes. Utilization of nuclear spins for memory and information storage is discussed as a natural alternative. A particular scenario consisting of spatially distributed constituted q-bits fabricated in a host structure is presented, where nuclear spin-spin coupling is mediated by laser controlled electron-nuclear Fermi contact interaction. Operations illustrating entanglement, nonlocality, and quantum control logic operations are presented and discussed.

A fermion coherent state representation is introduced and used to formulate an alternative algorithmic approach to quantum computation. The formalism permits exact mapping of the quantum dynamics to a Fokker-Planck representation for the time dependent probability distribution. Quantum computation is discussed in terms of probabilistic propagation of quantum trajectories.

1.10 H. J. Briegel

Quantum computing in optical lattices

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We propose the use of cold controlled collisions of atoms in optical lattices as a mechanism to introduce dynamic phase shifts required for quantum logic. In conventional lattices, with random occupation of the lattice sites, this mechanism could be used, for example, for spectroscopic studies of entangled Bell and GHZ states.

Recently, new ideas [1] for filling optical lattices with ultracold atoms have been developed, allowing for a highly regular occupation of individual lattice sites ("optical crystals"). This provides a new perspective for future quantum information experiments and for implementations of quantum computing with neutral atoms. In this talk, we will give an outline of these ideas. In particular, we will show how certain manipulations of the trapping potentials can be used to realize a class of highly parallel quantum gates. Such quantum gates could be used for quantum computing including an efficient implementation of quantum error correction.

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1.11 P. H. Bucksbaum

Quantum Control and Quantum Algorithms

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The ability to manufacture quantum wave functions with special properties can lead to new methods for bond-selective chemistry, quantum computing, and whole new fields of quantum technology. I will describe our work on direct control of the shape and motion of quantum wave packets in Rydberg atoms. This relies on recent advances in coherent, broadband, programmable optical pulses. We can produce wavepackets

with a wide range of shapes by excitation with a phase- and amplitude-shaped coherent light. The shape and motion of our wave packets can be tracked with good precision by energy-resolved quantum holography. We developed this as a quantum mechanical analog to classical spectral interferometry of optical pulses. In quantum holography, phase information is obtained through analysis of covariant fluctuations in the interference between the shaped wave packet and a well-characterized reference wave packet excited in the same atom. [1] Measurements of an atomic electron's radial wave function can be fed back to the laser in coherent control experiments where the target state is the sculpted wave function itself.[2] The laser system and the atomic beam can be a learning machine, capable of using feedback to teach itself how to make a particular shape or produce a specific type of wave packet motion. So long as the interaction between the light and the atom is linear, this feedback process converges rapidly. In a trial of this idea, we established a target shape for the wave packet, and then compared the amplitude and phase to a trial wave packet made with a shaped optical pulse. We corrected the shape of the optical pulse based on the differences between trial and target, and then iterated the process. Quick convergence was possible because of the linear relationship between the light and the wave packet. We are now extending this to nonlinear systems, such as Raman-active molecular liquids. These require more sophisticated feedback techniques such as the Genetic Algorithm. Ultimately these quantum control techniques show promise for the new field of quantum information algorithms. Information encryption, storage, and retrieval using quantum logical registers may be done using quantum control. Sophisticated multi-step algorithms, such as Shor's method for factoring large numbers, may also use quantum control techniques in some implementations.

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1.12 V. P. Bykov, poster

Nature of photocounts and laser detecting of coherent optical signals

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The report is devoted to account of the results of the author and collaborators papers [1-5], where nature of photocounts and peculiarities of the coherent signal detecting are investigated and new laser methods of such signals detecting are proposed either.

It is shown, that the coherent optical wavepackets, similar to ones, excited in lasers, do not contain any localized objects –photons–, which length is smaller, than the coherence length of the wavepacket. In this connection the problem of the origin of the photocounts or shot noise at the detecting of the coherent signals is arised,

since the coherence time of laser radiation does not correlate with characteristic time of photocount. The stability of weak electron flow, arising in detector under influence of the detecting radiation, is studied analitically and by numerical simulation. It is shown, that such flows have a specific Coulomb instability, similar to instability of small density electron plasma, leading in equilibrium conditions to Wigner crystallization [6,7]. In the nonequilibrium conditions of phododetectors this instability leads to the chaotic decay of the electron cloud into particular, one electron clots, which going from cathode to anode excite current splashes - photocounts - in the outer circuit of the detector.

Proposed picture of the photocounts (in other words, shot noise) origin, shows the possibility to suppress these instability by one or another way and, as a consequence, to detect radiation without photocounts and shot noise.

Some new, laser schemes of the coherent signal detecting are proposed. The instability of the electron system, mentioned above, in such schemes are practically absent. The photodetectors, based on such schemes, will have lowered level of the shot noise.

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1.13 H. Carmichael

Multi-Atom Effects in Cavity QED with Atomic Beams

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When an optical cavity mode interacts with the atoms in an atomic beam it is the beam density that is well-defined, not the number of interacting atoms. Often an "effective number of atoms" is quoted. The talk presents an analysis of the collective interaction strength made as a function of atomic beam density. A callibration of the "effective number of atoms" is proposed to define many-atom, few-atom, and one-atom regimes of cavity QED.

1.14 J. J. Carroll

Triggered Gamma Emission as a Precursor to a Gamma-Ray Laser

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A gamma-ray laser would provide coherent radiation at sub-Angstrom wavelengths from electromagnetic transitions between excited nuclear states. Even if the output radiation was isotropic, more of a gamma flash, simply the ability to trigger the emission of gamma radiation in a controllable manner could have important consequences. In addition, since the radiation would serve just to deexcite isomeric nuclei to their ground states, there would be no radioactive by-products: an isomeric material could provide a "clean" source of nuclear energy, much like a nuclear battery. These possibilities are suggested by unique advantages inherent in nuclear electromagnetic transitions that can provide exceptional energy storage. The basic concept for the gamma-ray laser was introduced in 1961, yet the interdisciplinary nature of the gamma-ray laser problem frustrated efforts for decades. In fact, several reviews over that period concluded that there was no known effective approach to achieve a gamma-ray laser, largely due to technological restrictions. Fortunately, new ideas have continued to be introduced and among those "optical" pumping, analogous to the approach seen in the ruby laser, has provided sustained positive results over the past decade. Experiments have shown that isomeric states of nuclei can be excited with photons from their ground states and that "induced gamma radiation" (IGE) can be triggered from long-lived isomeric states. A gamma flash or even a gamma-ray laser based upon these results remains feasible with the right isotope. This talk reviews the optical pumping approach, systematics that identified the first-ranked nuclide, and experimental demonstrations of triggered gamma emission.

1.15 A. A. Chernenko, poster

Amplification without inversion on the transition from autoionizing states of Yb atom

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The results of theoretical investigations of the small optical line form absorption (amplification) signal near the autoionizing (AI) Yb atom states belonging to the 4f(13)6s(2)6p electron configuration are reported. On the basis of numerical calculations of the nonstationary density matrix equations for three level atomic system, interacting with continuum, the time system behaviour under the variation of the excitation parameters and frequency detuning of testing radiation beam are determined. Effect of the small optical signal amplification without population inversion of the atomic levels studied are found. The spectral region and necessary conditions for the existence of amplification without inversion on transitions from the shown AI Yb levels depending on Fano parameters and noncoherent pumping power are determined. It was shown that the noninversion amplification gain in nonstationary regime was more higher than the stationary one. The first experimental results of practical realization of amplification without population inversion are discussed.

1.16 S. L. Chin

From intense femtosecond pulse propagation into white light laser

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Self-focussing and filamentation of an ultrafast intense Ti-sapphire laser pulse in an optical medium will lead to the generation of a plasma that stabilizes or prevents catrastrophic self-focussing. At the same time the interaction with the plasma through spatio-temporal self-phase modulation modifies the pulse's field and phase distribution such that the spectrum of the pulse is enlarged enormously. This transform the pulse into a broadband (supercontinuum) chirped pulse. Because the broadening happens to be in the visible region, it is a white light chirped laser pulse. In this talk, various new phenomena accompanying the propagation together with the justification of the white light laser through coherence length measurement will be presented. In particular, evidence of multiple refocussing in air and high field induced fluorescence some of which is due to laser induced trapped electronic states will be shown.

1.17 G. Cory

Quantum Computing Using NMR

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If one is ever built, a quantum computer will exploit the superposition principle to solve certain problems much more efficiently than any known algorithm for their classical counterparts. Important problems that benefit from such speedups include factoring large numbers, combinatorial searches, and simulations of quantum systems. We will describe the implementation of small prototype quantum information processors based on Nuclear Magnetic Resonance and illustrate its properties through two examples: a quantum simulation and quantum error correction.

In 1982, Feynman proposed that a quantum system would be more naturally and efficiently simulated by a computer based directly on the principles of quantum mechanics. By combining the general simulation methodology with average Hamiltonian theory we have implemented a practical scheme for quantum simulations by NMR. We will present experimental results from the first explicit simulation of one quantum system by another, a kinematics and dynamics of a truncated quantum harmonic and anharmonic oscillator.

To implement a large-scale quantum computation, quantum error correction will be required to compensate for the fragility of quantum coherence. The first experimental implementation of quantum error correction will be discussed to demonstrate the underlying principles. In addition, quantum information processing provides a precise language with which to pose questions concerning physical models of decoherence and to reduce these to experimental measurements. This may be illustrated by a quantum code that permits quantitative measurement of the spatial correlation of local fluctuating mean fields.

1.18 A. Czitrovszky

Photometric measurements of quantum efficiency using quantum two-photon field

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An existence of pairs of correlated photons from nonlinear parametric down conversion has made it possible to develop a technique for measuring the absolute value of quantum efficiency of the optical detectors, both in photon -counting and in analogue regimes, without using any standard light sources. A new technique for the measurement of quantum efficiency using single photomultiplier and avalanche photodiodes was evaluated. The principle of this method is based on a strong correlation existing between two entangled photons in space and in time that distinguishes this effect from other processes of nonlinear optics and light scattering. This calibration of quantum efficiency works the best for photodetectors in photon-counting regime since nonclassical properties of light in this process are revealed with better contrast for single photons. The presence on an optical radiation consisting of rigorously correlated photon pairs

with continuos distribution in a broad spectral and angular range - as a result of the interaction of pump radiation with the nonlinear crystal - makes it possible to determine the spectral distribution of the measured quantities of photodetectors. Correlated pairs of photons have been generated in a potassium dihydrogen phosphate nonlinear crystal pumped by an UV line of an argon laser for optical parametric downconversion. The nonlinear crystal was cut at type-I phase matching angle for production of degenerate and non-degenerate photons. In the first experiment (measurement of the quantum efficiency using a single photomultiplier) photon pairs were selected using a diaphragm, a narrow band interference filter, and focused on the surface of the photomultiplier to be tested. The determination of the quantum efficiency is based on the measurement of the ratio between the single- and double-electron peaks in its pulse-height distributions. In the second experiment (measurement of the quantum efficiency of avalanche photodiodes) the determination of the quantum efficiency is based on the measurement of the coincidence photon rate of two avalanche diodes registrating correlated photon pairs and photon rate on each photodetector.

1.19 P. Domokos

Quantum theory of a thresholdless laser

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Lasers, in which the spontaneous emission is efficiently suppressed into other than the laser mode, can exhibit thresholdless operation [1]. This can be achieved with microcavities that lead to a strong or, at least, a near to strong coupling between the radiation mode and the active medium. Standard laser models, e.g. the rate equation approach or any semiclassical approximation, are not valid to describe such a situation. On the other hand, simple cavity QED techniques do not apply because of the complexity of the system, basically, because of the high number of excited atoms in the mode.

We develop a quantum theory of a single-mode thresholdless laser. From the basic Heisenberg-Langevin equations, we obtain an approximate analytical solution to these operator equations. An efficient Monte-Carlo method is found to simulate the exact operator equations. The predictions of the analytical model for the intensity and the power spectrum are verified by a numerical calculation. We also show that our quantum model provides reliable results in the bad-cavity regime while the validity of the rate equations breaks down.

Finally, we apply the different models to the Nd-doped microsphere lasers at low temperatures [2], which are promising devices for a well-controlled thresholdless operation.

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1.20 R. Kh. Drampian

Generation of spatial solitons in self-focusing medium by laser beam with intensity modulated profile

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The generation of bright spatial solitons has recently become a subject of considerable interest because it opens a possibility of encoding information in the transverse structure of electromagnetic field. The spatial solitons are possible to realize particularly in nonlinear self-focusing medium. Transverse intensity modulation or aberration, as well as breaking of azimuthal symmetry of Gaussian beam leads to the formation of spatial solitary waves [1].

In this report we present the experimental results on break-up, in self-focusing Kerr medium, of a spatially self-phase modulated beam [2]. In the experiment the single-transverse-mode laser radiation with slightly elliptical Gaussian profile at wavelength 530 nm, pulse duration 20 nsec, power 10 kW and diameter 1 mm was focused into the first nitrobenzene cell with a length 25 cm. A slightly elliptical ring surrounding the central spot was observed in the far field for laser intensity 10^8 W/cm^2. The spatially modulated output beam (with the length of major and minor axes of ellipse 6 mm and 5.5 mm and diameter of inner spot 1.5 mm) from the first cell was focused into the second similar nitrobenzene cell to study its break-up.

The observed transverse profile near the exit window of the second cell consists from four concentric elliptical contours with major axis oriented at 45^0 to the vertical direction, superimposed by a number of spots in the center of ellipses, as well as by two bright spots lying at the ends of the long axis of the outermost ellipse.The measured length of major and minor axes of outermost ellipse was 2.5 and 2 mm, and the diameter of central and external spots was 100 and 300 μm. The formation of elliptical contours in self-focusing beam can be caused by spatial intensity modulation of pump beam profile and propagation instabilities. The generation of the pair of solitonlike beams lying on the outermost ellipse can be interpreted as a result of slight ellipticity of the outer ring in the profile of self-phase modulated beam [1]. The estimation of critical power and self-focusing length for spatially modulated beam by formulae of

ref. [3] gives the values 10^4 W and 10 cm confirming that self-focusing conditions were satisfied in the experiment.

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1.21 A. M. Fedotov

Dynamic Casimir Effect in Sudden Approximation

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Creation of photons in a cavity after sudden displacement of one wall is considered. Using both perturbation and non-perturbation technique we calculate average number of created photons, amplitude of vacuum-vacuum transition and amplitudes of creation of particular number of photons in different modes. Generally we are concentrated on the case of 1D cavity but some results are obtained for flat, cylindrical and spherical-shape 3D cavities. We show that under certain circumstances the number of created photons can be very high. From mathematical point of view unitary nonequivalence of quantum field theories in the cavities with different sizes is the reason.

1.22 M. Fleischhauer

Radiative atom-atom interactions in optically dense media

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The interaction of classical light with dilute atomic gases is ususally described by the well-known Maxwell-Bloch equations. This description fails however when the atomic gas becomes optically thick for some relevant resonance frequency. In this case reabsorption and multiple scattering of spontaneous photons need to be taken into account. Furthermore if the number of atoms per cubic wavelength becomes larger than unity, local-field corrections are needed to remove contributions from unphysical

interactions of different atoms at the same position. Starting from a quantum description of the atom-field interaction effective nonlinear single-atom Bloch equations for the atomic evolution are derived that take into account reabsorption and multiple scattering of spontaneous photons and local-field corrections. Effects of radiative atom-atom interactions such as superluminescence (amplified spont. emission), radiation trapping and its effects on optical pumping, the alteration of radiative decay rates and Lamb shifts in optically dense media as well as intrinsic (mirrorless) bistability are discussed.

1.23 R. L. Fork

Spatially Extended Modelocking

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We report progress toward realization of a type of laser oscillator modelocking we refer to as spatially extended modelocking. By spatially extended modelocking we mean the locking of the frequencies and phases of the complete set of modes of an array of spatially distributed, but densely packed, micro-laser oscillators. As a baseline configuration we take a square planar array of oscillators where the individual laser oscillators are separated by approximately one optical wavelength. Such an array is similar in the properties of the emitted electromagnetic field to a pulsed microwave phased array exhibiting true time delay. The system is different, however, in the means by which the emitted field is configured, and agilely reconfigured, in space and time. Another important difference is that the system operates at wavelengths that are some four orders of magnitude shorter than the typical microwave wavelength. The spatial and temporal resolution that can be accessed are correspondingly enhanced. The femtosecond temporal domain and the optical wavelength spatial domain become accessible, e.g..

Such a laser system is difficult of realization because of the complex control and fabrication issues encountered. The number of elements, the dense packing of elements, the precise temporal resolution required, heat removal, and other constraints pose major challenges. The potential applications, however, are significant. The ability to form multiple time resolved optical beams, and to steer those beams in an agile manner can be applied, for example, to many sensing and display tasks. We are pursuing a program that addresses basic and practical issues that must be solved in realizing such a system. We describe these issues and progress toward their solution.

In particular, we have experimentally and theoretically examined periodic dielectric structures that provide means for agile electronic control of both phase delay and group delay of each element in the array. The control devices have dimensions compatible with the micro-laser oscillators that would make up such a system. These control devices appear to offer one of the most likely means of implementing the modelocking

we describe. We present data taken using pulses of 100 femtoseconds duration and compare that data with numerical simulations of the expected transmission, reflection, group, and phase delay of these basic structures. Means of constructing systems of these devices that could provide agilely adjustable arrays with dimensions of centimeters and larger are examined.

1.24 J. D. Franson

Nonlinear Optics at Low Intensities using Photon Exchange Interactions

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Nonlinear optical effects normally require high-intensity fields containing many photons, since the electric field associated with a single photon is very weak. Nonlinear optical effects involving only two photons have been observed previously using high-Q cavities and atomic beams or traps. We are investigating a new approach for the production of nonlinear phase shifts at single-photon intensities that is based on the use of exchange interactions between two photons. We show that the probability of there being two virtually-excited atoms in a medium is twice as large when two non-resonant photons propagate in the same medium as compared to the case in which they propagate in two separate but identical media. We apply a short laser pulse to the medium to produce a phase shift in the excited states of the atoms. Since the number of excited atoms is larger when both photons are in the same medium, this gives rise to a nonlinear phase shift that can be used for the construction of a controlled-NOT quantum logic gate. We will present the theory of exchange interactions of this kind and discuss the status of an experiment intended to demonstrate the operation of a controlled-NOT logic gate using two photons propagating through a sodium vapor cell.

1.25 A. L. Gaeta

Catastrophic Collapse of Ultrashort Pulses in Condensed Matter

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Understanding the propagation of high-power femtosecond laser pulses in optically transparent solids is important for a wide range of intense-field interactions including plasma formation, laser damage, and frequency conversion. Self-focusing is perhaps the most fundamental nonlinear optical process that can occur when a pulse propagates through a material. For pulses in the femtosecond regime, the self-focusing behavior can exhibit complex nonlinear dynamics. Theoretical investigations [1] have used the three-dimensional nonlinear Schrödinger equation (NLSE) model to describe self-focusing in the femtosecond regime. It is found that the presence of even small amounts of dispersion in the index of refraction results in spatial and temporal dynamics that are completely different from the dynamics of the long-pulse regime. A striking prediction of this model is that even for input powers substantially greater than the critical power P_{cr}, catastrophic self-focusing is suppressed and the self-focused ultrashort pulse splits into two pulses.

We have verified this pulse splitting behavior [2] and showed theoretically and experimentally that the self-focusing of ultrashort pulses is invariably accompanied by the breakdown of the slowly-varying envelope approximation [3], even for pulses that are initially much longer than an optical cycle. At higher powers, the pulse undergoes catastrophic collapse and other nonlinear processes such as multi-photon absorption, plasma formation, and Raman scattering play an important role. We describe our recent experimental and theoretical results on the spatial and spectral dynamics of the pulse in this regime.

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1.26 P. García-Fernández

Quantum noise reduction in singly resonant optical devices

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Quantum noise in a model of a singly resonant frequency doubler including phase mismatch and driving in the harmonic mode is analyzed. The general formulae of the fixed points and their stability as well as the squeezing spectra calculated linearizing around such points are given. General criteria to optimize the noise suppression performance are elaborated. The optimum working point for squeezing in the fundamental mode is located near the first turning point of the dispersive bistability induced by cascading of the second order nonlinear response. The nonlinearities induced by conventional crystals appear enough to reach it being the squeezing ultimately limited by the escape efficiency of the cavity. In the case of the harmonic mode both, finite phase mismatch and/or harmonic mode driving allow for an optimum dynamic response of

the system, something not possible in the standard phase matched Second Harmonic Generation. The squeezing is then limited by the losses in the harmonic mode, allowing for very high degrees of squeezing because of the nonresonant nature of the mode. This opens the possibility of very high performances using artificial materials with resonantly enhanced nonlinearities. It is also shown how it is possible to substantially increase the noise reduction and at the same time to more than double the output power for parameters corresponding to reported experiments.

1.27 A. Gatti

Quantum Entangled Images

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In the last few years our group studied the quantum aspects of the spatial patterns that emerge in the radiation field when it propagates through nonlinear optical media [1]. These aspects, which are in turn related to the spatial features of squeezing, are intimately linked to one of the most profound and intriguing concepts of quantum mechanics, i.e. entanglement. Optical patterns generated by nonlinear optical processes such as, for example, parametric down-conversion, arise from the interference of entangled waves.In this context, entanglement is not studied on the level of single photon pairs but, rather,on the level of mesoscopic/macroscopic radiation beams.

We show that, by using an optical parametric amplifier and an appropriate arrangement of imaging lenses, it is possible to produce a pair of images which are quantum mechanically entangled one to each other. Precisely, in the output one has an amplified version of the input image (signal image), and a symmetrical idler image. In the limit of large amplification, the two images have not only the same intensity distribution, but also the same local intensity fluctuations. By measuring the intensity fluctuations in the idler image and by introducing an appropriate feedback loop, the intensity fluctuations of the signal image can be reduced much below the shot noise level.

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1.28 R. Glauber

Coherence and Correlations in Ultracold Atomic Fields

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The statistics of cold atoms and the coherence of their fields are described by a hierarchy of correlation functions analogous to those of quantum optics. We examine the first and second order correlation functions for both fermions and bosons, with and without interactions, and discuss a number of their properties.

Weak bosonic and fermionic fields may possess similar coherence properties, but those properties begin to differ greatly as the field occupation numbers become degenerate. In particular, while strong bosonic fields may still exhibit all orders of coherence, even first order coherence becomes inaccessible to stronger fermionic fields. Substantial coherence lengths and times can be achieved for fermionic fields only at the expense of lowering atom densities.

Statistical calculations for fermionic fields, we show, can be carried out by techniques based on formally defined coherent states, together with the consistent use of an algebra of completely anti-commuting numbers (Grassmann algebra). Approached in this way, calculations carried out for fermionic fields reveal many close parallels with the calculations carried out in quantum optics, and for bosonic fields more generally.

1.29 A. A. Kalachev

Long-lived optical superradiance in the van Vleck paramagnets

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As its known, conventional Dicke superradiance has a serious drawback associated with its self-starting and, therefore, uncontrollable nature, which hinders practical applications of this phenomenon. The opportunity of intervening in the process of collective spontaneous emission and controlling this process was opened up after observation of triggering superradiance. The triggering superradiance pulse is emitted by an inverted resonant medium after action of injection pulse at earlier moments of time and in another direction than conventional Dicke superradiance pulse. This work is devoted to the problem of control of superrradiance process in Van Vleck paramagnets doped with ions of rare-earth metals (such as LaF3:Pr3+, YAlO3:Pr3+ and

so on). These crystals are strong candidates for creation of optical memory devices based on the long-lived photon echo. The time of data storage in such resonant media (which is determined by lifetimes of metastable hyperfine sublevels of a ground electron state) may reach several hours. This circumstance may be used for observation of long-lived superradiance (LLS). The signal of LLS is generated after action of inverting p-pulse (reading pulse) on the resonant medium that stores information about writing pulses as nonequilibrium population grating of metastable levels. The theory of LLS is developed and optimal conditions of that effect are determined.

1.30 A. E. Kaplan

Laser-powered single-atom motional oscillator

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A weak cw laser radiation can induce large self-sustained motional oscillations of a trapped single particle. The effect is due to Doppler-induced instability of the particle subjected to radiation pressure of light which is blue-shifted off absorption resonance. This oscillator can be nearly thresholdless. With milli-watt pumping, the oscillations exhibit huge hysteresis and may easily reach a trap-size orbit. Feasible applications include "Foucault pendulum" in a trap, rotation sensor and inertial navigation, single atom spectroscopy, isotope separation, atomic clock, etc.

1.31 A. V. Kir'yanov

Study of Phase Grating Recording in 4-keto Bacteriorhodopsin Using Phase-Modulated Beams Technique

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Peculiarities of the phase grating recording in polymer films containing 4-keto Bacteriorhodopsin are investigated under absorption saturation. The phase-modulated beams technique is used to measure photoresponse from the films in real time. Three maxima of the photoresponse are detected: The two first (at 1 and 10 sec) correspond to the positive amplitude of the phase grating, whereas the third (at 1 min) - to the negative one. The phenomenon is explained, as the theoretical analysis shows, by spatial distortions of the grating, resulting in the fundamental spatial harmonic sign exchange. These maxima, we believe, correspond to three photocycles in the 4-keto Bacteriorhodopsin molecule, for which a novel scheme is suggested. The results of the theoretical simulations are shown to be in good agreement with the experiments.

1.32 T. Kiss

Detection of non-classical oscillations in phase-space by cascaded optical homodyning

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Much attention has been paid in the past few years to different measurement schemes capable to collect statistical data in order to reconstruct the complete quantum state of a single mode traveling light field [1].

In our recent proposal [2] we have combined two experimentally feasible schemes, balanced [3] and unbalanced [4] homodyning. In the cascaded arrangement the first step is to set the target phase-space point by an unbalanced scheme, then in the second step a phase-randomized balanced homodyne detector serves as a high efficiency indirect photon detector. We derive the universal sampling function of the scheme analytically and show that it possesses a simple structure, which is independent of the location of the phase-space point.

Numerical simulations suggest that non-classical oscillations in phase-space distributions can be detected with the method by testing only a few well-chosen phase-space points. This aspect becomes important for the distinction of coherent superposition of quasi-classical states (Schrödinger cat states) from statistical mixtures.

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1.33 P. L. Knight

Decoherence limitations to implementations of quantum logic

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Quantum information processing rests on our ability to manipulate quantum superpositions through coherent unitary transformations. In reality the quantum information processor (a linear ion trap, or cavity qed implementation for example) exists in a dissipative environment. Dephasing, and other technical sources of noise, as well as more fundamental sources of dissipation severely restrict quantum processing capabilities. The strength of the coherent coupling needed to implement quantum logic is not always independent of the dissipation. We discuss how to implement entanglement in a dissipative environment. The limitations these dissipative influences present will be described and the need for efficient error correction noted in practical application.

1.34 O. Kocharovskaya

Coherent optical control of gamma-ray nuclear spectra

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A compound nuclear electron system driven by a coherent optical field and probed at the gamma-ray Mössbauer transition is analyzed for the first time. The possibility of optical control of the Mössbauer spectra is predicted. It provides the basis for a new branch of spectroscopy: laser-Mössbauer spectroscopy, and opens the prospects for a realization of a gamma-ray laser.

1.35 M. I. Kolobov

Noiseless amplification of optical images

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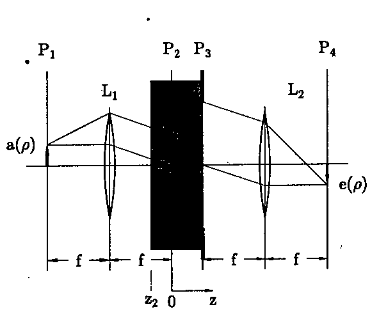
Noiseless amplification of temporal optical signals has been studied in the literature both theoretically and experimentally. Its spatial counterpart for noiseless amplification of optical images was proposed by Kolobov and Lugiato in Ref. [1] for a cavity-based geometry. Here we shall consider a traveling-wave version of the ring-cavity noiseless image amplifier. This modification is, on one hand, more realistic for practical implementations, on the other hand, has several advantages over the cavity-based scheme, such as greater spatial bandwidth, Ref. [2].



The scheme of a traveling-wave parametric image amplifier is shown in the figure. An input image is imprinted into a faint spatial modulation of the wave-front of a coherent light wave, located in the object plane P_1. The lens L_1 performs a Fourier transform of the input image into the Fourier plane P_2 laying at the distance z_2 from the input plane of the parametric crystal. This distance is found from the condition of the optimum phase matching in the scheme. The nonlinear crystal of length l plays the role of a traveling-wave optical parametric amplifier (OPA).

The parametric interaction takes place between the signal wave of frequency ω, carrying the input image, and the plane monochromatic pump wave of double frequency, illuminating the input face of the crystal. The output lens L_2 performs the back Fourier transform of the amplified image into the photodetection plane P_4.

As in Ref. [1], we assume that the amplified image is recorded by a dense array of small photodetectors, *pixels*, of a finite area S_d, during the observation time T_d. Using the quantum photodetection theory, we evaluate the mean number of photoelectrons $\langle N_I(\vec{\rho},t)\rangle$ registered by a pixel centered at the point $\vec{\rho}$, its variance, $\sigma_I^2(\vec{\rho},t)$, and the signal-to-noise ratio R_I of the amplified image, $R_I = \langle N_I(\vec{\rho},t)\rangle^2/\sigma_I^2(\vec{\rho},t)$.

The equivalent quantities $\langle N_O(\vec{\rho},t)\rangle$, $\sigma_O^2(\vec{\rho},t)$, and R_O in the object plane describe the signal and noise of the input image. To characterize quantitatively the amount of extra noise added by the amplifier we study the noise figure F of our scheme,

$$F = R_O/R_I.$$

Since the signal-to-noise ratio cannot be improved by a linear amplifier, the noise figure is not less than unity, $F \geq 1$. The case of $F = 1$ corresponds to noiseless amplification. We formulate the criteria for noiseless operation of our scheme and investigate its physical parameters such as resolving power, et cetera.

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[2] I. V. Sokolov, M. I. Kolobov, and L. A. Lugiato, "Quantum fluctuations in traveling-wave amplification of optical images", submitted to Phys. Rev. A.

1.36 K. V. Krütitsky

Microscopic theory of the interaction of ultracold dense Bose and Fermi gases with electromagnetic field

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We present the rigorous microscopic quantum theory of the interaction of ultracold Bose and Fermi gases with the electromagnetic field of vacuum and laser photons. The main attention has been paid to the consistent consideration of dynamical dipole-dipole interactions. We have shown that the retardation effects influence significantly the behaviour of the atomic ensemble in the radiation field. The theory developed is shown to be consistent with the general principles of the canonical quantization of electromagnetic field in a medium.

Starting from the first principles of QED we have derived the general system of Maxwell-Bloch equations for atomic creation and annihilation operators and the propagation equation for the laser field which can be used, for instance, for the self-consistent analysis of various linear and nonlinear phenomena in atom optics at high densities of the atomic system. We have shown that all equations which are used up to now for the description of the behaviour of an ultracold atomic ensemble in a radiation field can be obtained from our general system of equations making use of different assumptions concerning the magnitude of the density.

As an example of the application of our general theory, we have considered the diffraction of a beam of ultracold Bose atoms by the standing laser wave. It is shown that with the increase of the initial density of the atomic beam the intensities of different diffraction orders may decrease or increase depending on the sign of the detuning of the laser frequency from the frequency of the single atom resonance. We have also shown that the angle of diffraction for different orders is defined by the refractive index of the atomic ensemble which is a function of the density.

1.37 P. Kumar

Spatially broadband parametric amplification: quantum-noise correlations and noiseless optical amplification of images

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The success of many precision measurements often depends on the use of amplifiers. The sensitivity of these measurements is, therefore, limited by the amount of noise that the amplifier adds to the signal. For electronic and microwave signals, the noise floor is determined by thermal fluctuations. At optical frequencies, however, the thermal noise becomes negligibly small. In that case, the noise floor of a phase-insensitive amplifier, i.e., a linear optical amplifier whose gain does not depend on the signal phase, is determined by a fundamental quantum limit, which arises ultimately from zero-point field fluctuations. In a typical optical amplifier, these fluctuations cause spontaneous emission of photons, resulting in added noise to the signal. For a coherent-state input, the degradation of signal-to-noise ratio at the output approaches 3 dB for high gain. The noise owing to the zero-point fluctuations, however, can be avoided by employing a proper phase-sensitive amplifier (PSA) that either amplifies or deamplifies the input signal depending on its phase [C. M. Caves, Phys. Rev. D **26**, 1817 (1982)]. This noise-free property of a PSA is related to the fact that every act of spontaneous or stimulated emission in such a device produces a pair of correlated photons, whose quantum correlation can be utilized for noise cancellation.

The quantum correlations imposed by a PSA have been exploited to produce non-classical states of light. It has also been demonstrated that a PSA does not add any noise while amplifying continuous-wave or pulsed time-domain signals. A practical realization of a PSA is a traveling-wave optical parametric amplifier (OPA), which provides broadband gain not only in the temporal domain, but also in the spatial domain. The spatially-broadband nature of the OPA suggests its potential use for noiseless amplification of spatial-domain signals, i.e., images, as well as for sub-shot-noise microscopy [M. I. Kolobov and P. Kumar, Opt. Lett. **18**, 849 (1993)].

The spatially-broadband gain of the OPA has been exploited previously in classical imaging experiments, such as parametric up-conversion of infrared images to the visible, edge enhancement, and time-gated image recovery. In contrast, our work addresses the quantum-noise issues in image amplification. Recently, we measured quantum correlations between the corresponding spatial frequencies of a parametrically amplified (signal) image and its generated conjugate (idler) image, and found the direct-detected difference noise to be $\simeq 5$ dB below the shot-noise level [Optics Express **2**, 84 (1998)*. Here, we present observation of noiseless amplification of an image by a phase-sensitive optical parametric amplifier. * http://epubs.osa.org/oearchive/source/4000.htm] This research was supported in part by the U.S. Office of Naval Research.

1.38 Yu. E. Lozovik

Femtosecond Spectroscopy of Porous and Cluster Materials

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Large photoinduced transmission and reflection is observed in porous silicon (PS) and C60 films in the spectral region 1.6-3.2 eV by using a femtosecond pump-supercontinuum probe technique. The measured nonlinear transmission and reflectivity spectra of PS have a fast component 500 fs. The spectral structure and relaxation dynamics of the short-lived component with slowing down of relaxation rate at 1.95 eV and 2.5 eV are suggestive that relaxation processes correspond to nanocrystallites defects scattering. Observed coherent phonons vibrations at 518 cm^{-1} and 480 cm^{-1} may be attributes with the size of crysttallites 5 nm and due to presence of a disorder phase, respectively. The ultrafast relaxation of excitations in a C60 film was probed in the energy range 1.6 - 3.4 eV by pump- supercontinuum probe technique with 40 fs time resolution. The relaxation rate shows pronounced spectral dependence with maximum at 2 eV in the region of photoinduced darkening and at 2.4 eV in the region of photoinduced bleaching. It is found that the ultrafast relaxation rate decreases with increasing pumping pulse intensity. The shape of the optical density variation at zero time delay in the region of interband transitions at 2.3 - 3.4 eV is similar to the shape of the second derivative of the stationary absorption spectrum. We propose that this may indicate the creation of a random electric field in the sample during the absorption of the pump pulse. We suggest that the decrease of the relaxation rate with the increase of pumping pulse intensity results from extra-heating of the carriers in hu and t1u bands due to internal conversion from higher excited states, which are populated by two-step photon absorption of the intense pump pulse. Coherent excitation of phonons in the 60 - 300 cm^{-1} frequency range were detected over a wide spectral probe range. An oscillation with a frequency of 118 cm^{-1} indicates that the nonequilibrium dimerization of C60 molecules takes place following optical excitation. The full splitting of the H(1) intramolecular oscillation mode is observed clearly, which demonstrates that a strong deformation of the molecules upon photon absorption takes place.

1.39 Yu. E. Lozovik

Excitation of an atom in $1D$ cavity with moving walls

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The interaction of a two-level or a three-level atom with one mode of quantized radiation field in $1D$ cavity with moving walls is considered in rotating wave approximation. We predict effect of excitation of the atom and show that the mechanism of excitation does not reduce to absorption of photons created due to the dynamic Casimir effect. The limiting cases of sudden displacement and adiabatic movement of the walls are studied. Our results are also applicable to the atom moving in a long $2D$ cavity with variable section.

1.40 A. Maitre

Transverse classical and quantum structures in a triply resonant OPO

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Nowadays with the development of video signals, it becomes important to know if there is any fundamental limit for the resolution of optical images. Optical images are currently monitored by sensors like CCD cameras which record intensities on their different pixels. If the light is in a coherent state, the cross-correlation between different pixels is zero and each pixel exhibits a local shot noise. These quantum fluctuations of light impose limitations to the visibility and quality of optical images. Multimode non-classical states of light, characterized by a local squeezing or non-classical correlations between pixels, can improve the resolution of measurements in optical images. OPOs operating simultaneously on many transverse modes are good candidates for generating such multimode non classical states.

We present here an experiment performed for studying the transverse patterns produced in a OPO and their quantum noise properties. The cavity is triply resonant and quasi degenerate for transverse modes. A KTP type II crystal is used as the amplifying medium. It consists of two inverted crystals in order to compensate the walk off. The OPO is pumped at 532nm by a single mode cw laser and produces signal and idler which are almost frequency degenerate around 1064nm. We have observed different kinds of patterns with completely different transverse structures for signal, pump and idler. We found that the pump does not impose its shape, but that its size has a large influence on the patterns. In such an OPO, many transverse modes are coupled in the cavity by the nonlinear interaction. This study of classical patterns is the first step in the study of quantum structures and will be followed in the near future by the measurement of quantum correlations between different parts of the patterns.

1.41 Z. G. Melikishvili, poster

Quasistationary laser plasma

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The methods of emission and laser absorption spectroscopy are used to investigate processes of formation and destruction of laser plasma in an atmosphere near the carbon solid target. The plasma is received with the help of train of giant pulses of waveguide neodymium laser, consisting of 40 optically connected spoke-like active elements. The radiation of the laser (1.06 microns) fell on the target surface without focusing. The laser has following parameters: the total energy in the pulse train is approximately 30 J, the repetition rate of giant pulses - 100 kHz and duration of whole pulse train - 0.2 microsecond. The high homogeneity of the field distribution in the cross section of the laser radiation beam and high repetition rate of giant pulses make possible the quasistationary laser plasma with relatively large sizes (up to 0.2 cubical cm). Sounding plasma by radiation of He-Ne laser determines speed of distribution of front of plasma at the various moments of time. Average speed of flight of the plasma front is 60 m/sec, which testifies the burning of carbon in the plasma - atmosphere layer. The luminescence of plasma is quasistationary during action of a train of giant pulses. On a background of quasistationary luminescence of plasma the intensive lines of anti-Stokes components in red and green spectral areas caused by the Stimulated Raman Scattering of laser radiation are received. The spectrum of Stimulated Raman Scattering testifies the presence in a boundary layer plasma - air of the carbon dioxide molecules.

1.42 S. Meneghini

Atomic beams in longitudinally modulated light crystals

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Atom optics attracted in recent years considerable interest due to the fundamental nature of the experiments as well as due to the possible applications of the new techniques that have been developed in areas like lithography. One of the simplest experiments realized is the scattering of an atomic beam on a standing light field. Due to the extreme flexibility of classical optics we can model the light crystal almost into any form. It can be real or complex, can be time dependent or have a complicated spatial structure. While the dynamics in the simplest possible configurations is well known, not much attention was paid to complex potentials or potentials with strong longitudinal modulation. We present a detailed study of the dynamics of an atomic beam when the potential is made complex due to the inclusion of losses of the atoms (done by relaxation from a (meta-)stable into the unobserved level). We assume that the light crystal is periodic in transversal direction and strongly modulated in the longitudinal direction. The analysis shows how one or several significant changes (sequence of "switchings") of the light crystal properties influence the transversal distribution of the beam and how it influences the momentum distribution of the atomic beam.

1.43 P. Meystre

Optical Control and Entanglement of Matter Wave Fields

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We discuss the optical manipulation and control of the quantum state of bosonic matter-wave fields. In particular, we discuss a system analogous to the nondegenerate optical parametric amplifier, except that instead of coupling various modes of the radiation field, we consider the coupling between a quantum degenerate atomic field and an optical field, so that instead of photon pairs, what is involved is the generation of correlated atom-photon pairs. The talk will emphasize how this system can be used to optically manipulate and control the statistical properties of matter waves, and also generate quantum correlations and entanglement between macroscopically exited optical and matter waves. Finally, the application of this work to recent superradiance experiments by Ketterle et al in Bose-Einstein condensates will be briefly discussed.

1.44 P. Meystre

Recent Progress in Nonlinear Atom Optics

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The first theoretical study of nonlinear atom optics was reported by our group in 1993 [PRL 71, 3271 (1993)], but its experimental realization had to wait until five years later. The NIST group of W. D. Phillips et al has now demonstrated four-wave mixing of matter waves [Nature 398, 218, (1999)], and the MIT group has observed nonlinear wave mixing and superradiance in a Sodium condensate [W. Ketterle, private communication (1999)]. These results serve as a strong motivator to carry out further theoretical work on nonlinear atom optics. The talk will review some of our recent results on this topic, including the study of the build-up of matter-wave side modes from noise in Sodium condensates, and the application of matter-wave four-wave mixing to atom holography.

1.45 M. Mlejnek

A Dynamic Spatial Replenishment Scenario for Femtosecond Pulses Propagating in Air

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Recently, the nonlinear Schrödinger equation extended to include ionization and light – weak plasma interaction was used to explore numerically the striking observation of long, filamentary propagation of femtosecond pulses in air. It seems like an interplay of plasma induced defocusing and Kerr induced SF is responsible for this behavior. The two simple limits of this interplay are the self-waveguiding picture in which the pulse creates its own plasma waveguide, and the moving focus model in which the plasma defocusing plays no significant role in the propagation.

However, more detailed understanding of the dynamics is needed, and the numerical simulations can be of paramount importance in the clarification of the mechanisms behind this phenomenon. Based on numerical simulations, a rather dynamical picture arises in which the most intensive part of the self-focusing pulse generates plasma which then defocuses the tail of the pulse. The pulse loses its energy during this process and, eventually, the maximum intensity of the pulse is not sufficient to generate enough plasma to affect the pulse propagation significantly. The trailing part of the pulse, after being deflected by plasma, can have enough power to re-self-focus again, thus leading to another pulse appearing on the trailing edge of the field. This scenario, which can repeat several times, was termed as dynamic spatial replenishment.

Experimentally measured features, such as plasma yield, existence of conical emission, and propagation past the linear focus (in the focusing geometry) agree, at least qualitatively, with the numerical simulations. Clearly a rigorous modeling of the the wealth of the spatio-temporal behavior poses a challenging task by requiring a simultaneous treatment of self-focusing and plasma induced defocusing. This requires very intensive computational demands, and one can only expect a qualitative agreement due to the lack of accurate models for the light-matter interaction and parameters. So far, the numerical simulations were performed under the constraint of radial symmetry. In the experiments, however, it was observed that for higher input peak powers the initially radially symmetric field breaks up into several filaments thus losing its radial symmetry. In this talk we shall also report on the studies of the the evolution of initially perturbed transverse super-Gaussian fields which break into multiple filaments, and discuss their subsequent propagation.

1.46 F. Morales

Harmonic generation in presence of a multimode laser field

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We calculated the spectrum emitted by a two level atom driven by a strong laser. The pumping field is chosen as the superposition of several modes with arbitrary amplitude and frequency slightly different. The spectrum is strongly affected by the non monochromatic nature of the pump and shows the presence of a larger number of lines than in the case of a monochromatic field. The temporal evolution of the intensity of the emitted harmonics suggests it is possible to build short pulses of the harmonics at high frequency.

1.47 A. Mysyrowicz

Formation of a conducting plasma channel in air by self-guided femtosecond laser pulses

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We report the measurement of a conducting channel in air produced by self-guided femtosecond pulses (filaments). These filaments are created by pulses from a Ti:sapphire chirped-pulse-amplification laser system at 800nm with energies per pulse between 1 and 12 mJ and a duration of 120 fs. A spectacular decrease of the air resistivity is detected between 2 electrodes after passage of the self-guided pulse, over a distance which can exceed 150 cm. The estimated electron density in the short-lived plasma is compared to predictions from a 3-d numerical simulation of pulse propagation that includes the nonlinear Kerr effect and multiphoton ionization.

1.48 G. Petite

Understanding the Effects of Ionising Radiation on Matter with Ultrashort Pulsed Lasers

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In this paper, we will discuss how ultrashort pulsed lasers can help solving a number of problems pertaining to the effects of ionising radiation in matter, and particularly to the question of point defect creation in insulators. We first show how the state of matter reached a few tens of femtoseconds after the passage of a high energy particle (electron, ion, hard X ray or gamma photon) for which the energy deposition is essentially electronic resembles that obtained at the end of a high intensity femtosecond laser pulse. We then compare the orders of magnitude of the doses deposited with intense lasers to that obtained with other particles. Ultrafast optical pump/probe techniques can thus be used to study the mechanism leading from electronic excitation to point defect formation. We will essentially describe the results obtained using two different methods : Transient Fourier (or Frequential) Interferometry which can be used to monitor the free carriers kinetics, and transient absorption, which is used to observe in real time the formation of point defects. These methods are applied to a number of insulators, and we show that different characteristic behaviours are observed ranging from ultrafast trapping (mean time : 150 fs) of the electronic excitation associated with the formation of a self-trapped exciton (in quartz) to free carrier lifetimes of the order of 100 ps for other materials, for which there is no strongly bound STE known. We show, on the basis of these studies, that the elastic properties of the material is the relevant parameter to classify the studied insulators, whose behaviour is essentially determined by the lattice relaxation energy associated with the charge trapping. Finally, we discuss the precautions to be taken when translating the results obtained using lasers to other type of excitations.

1.49 L. A. Rivlin

Is the Photon Mass Zero ?

(Extraordinary photon behaviour in context of cavity electrodynamics)

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We discuss the mass-like behaviour of photons in real wave fields which cannot be represented by a single idealized unlimited plane wave. The nonzero rest-mass of such a photon actually exists due to standing field constituents and originates from the work performed in opposition to the light pressure of zero-point vacuum fluctuations while raking them together from free unlimited space into real spatially restricted field. In accordance with this the field vectors possess a longitudinal components and the propagation velocity is less than c. These extraordinary features of photons belonging to real wave fields manifest itself especially clear in the case of intracavity fields (for instance, in the waveguide modes). A set of thought experiments shows that considered inertial and gravitational photon mass is indistinguishable from the standard rest-mass of an usual massive body. Heuristic prospects for these results are assessed.

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1.50 L. A. Rivlin

Cold Atoms as a Source of Monochromatic and Coherent Nuclear Gamma-Radiation

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Current achievements in deep cooling and confining of neutral atoms open prospects of strong control of radiative gamma processes (both spontaneous and induced ones) in atom nuclei. Most descriptive consequence of atom cooling is a drastic narrowing the Doppler gamma lines of nuclei which leads to a set of important eventual after-effects.

First of all the Doppler line narrowing may be set as a ground of flexible method of nuclear spectroscopy alternative to the known Mössbauer approach. This method deals with spontaneous radiative processes in ensembles of free nuclei collected into cooled confined beams with the monochromatic inhomogeneous linewidth tending to a natural value.

An example of coherent radiative processes is nuclear gamma-ray lasing in cooled nuclear ensembles which is based on making use in positive manner both Doppler line narrowing needed for gain heighting and also recoil effects which accompany every radiative transition in free nuclei and give birth to various remarkable consequences, namely, -

1. the appearance of hidden inversion without an excess of excited nuclei;
2. the opportunity for noncoherent X-ray pumping according to a nonstandard two-level scheme;
3. the feasibility of cleansing the nuclear ensemble of undesired ingredients which raise the lasing threshold;
4. the feasibility of an intense gamma-burst emission by means of dynamic control of photon losses;
5. the appearance of anisotropic gamma-photon flux amplification and unidirectional radiation output without any reflecting mirrors; etc.

We present examples and quantitative estimates of various experimental realizations.

1.51 L. A. Rivlin

Transmission of Cold Atom Interference Pattern through (2+1)D Potential Well

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Current progress in the cold atom confinement technique, in particular, in experiments on atom waveguiding incites to resume attempts to transmit the psi-function images (de-Broglies pictures = dBp) through multimode (2+1)D potential wells (= particle waveguides) [1]. Any complicated coherent atom pattern at a waveguide input (input dBp) can be expanded in a series by means of (2+1)D well eigenfunctions. Running waves transfer information on transverse structure, amplitude and phase of the series terms along a waveguide to its output. Interference of psi-functions related to various terms at the output cross-section of a waveguide (i.e. a terminal dBp) in general shall not reproduce the input dBp because of the waveguide dispersion which results in complete difference of output phase relations between various modes in comparison with that of input ones. It is shown in paraxial approximation that in a multimode waveguide (i.e. in a potential well with cross dimensions considerably exceeding de-Broglie wavelength) some points exist remote from input where the phase difference of whichever mode pair is equal to that at the input added by integer number of 2pi . Thus at these synphase points which are periodically distributed along a waveguide the superposition of running waves reproduces the input interference pattern or, in other words, the input dBp is regularly transmitted as a whole through a particle waveguide. Calculations are made for various types of transverse potential well. Optical image transmission through a single multimode waveguide was already experimentally demonstrated using a monochromatic light [2]. It is of interest to fulfill such an experiment with de-Broglies waves making use of cold atoms and ultracold neutrons.

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1.52 B.-U. Runge

Magneto-optic Studies of Superconductors down to Nanosecond Time Resolution

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Optical methods offer an intrinsic high potential for experiments with excellent spatial and in particular also temporal resolution. Using either the Faraday or the magneto-optical Kerr effect, this advantage can be extended to the investigation of magnetic phenomena on small length and short time scales. We have done this by application of pump-probe techniques in combination with pulsed lasers. Several examples for investigations of superconducting samples are presented in this talk.

In our case the magneto-optical method is based on the Faraday effect, i.e. the rotation of the polarization plane of linearly polarized light which passes a magneto-optically active layer (EuS or iron garnet) exposed to the magnetic field of the adjacent superconductor. Since the rotation angle depends on the magnetic field, one can visualize the flux distribution as optical contrasts in a polarization microscope. In this way one obtains important information for the understanding of the flux structure, e.g. in thin films of high-temperature superconductors. Defects in the superconducting material which possess a lower critical current density disturb the homogeneous penetration of magnetic flux into a sample when an external magnetic field is applied after zero field cooling. This is true even if the defects are below the sample surface or when the superconducting sample is covered by a thin protective layer of another material, e.g. gold.

For studies of the dynamics of magnetic flux in a superconducting sample a pump-probe set-up has been used. An instability which causes magnetic flux to enter the sample in dendritic form [1] is triggered by local heating with a focused ns laser pulse. Part of the beam is separated by a beam splitter, passed through a variable delay line of suitable length and used for illumination of the sample. The experiment is repeated and images are acquired for different delay times thus allowing to determine the spreading velocity of the flux front. For YBCO thin films a spreading velocity of $(5\pm2)\times10^5$m/s is found which is an order of magnitude higher than the velocity of sound. These flux structures are not only of fundamental interest, but are also important from the application point of view, because they even form spontaneously and then can lead to a local destruction of the superconducting film. For further investigations of such magnetic phenomena on even shorter time scales magnetooptic experiments in the picosecond range are underway.

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1.53 V. V. Samartsev

Long-lived photon-echo and optical phase memory

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The contemporary state of the investigations of photon echo and other optical transient phenomena is discussed in this report. Since the phase memory lays in base of all these effects, they may be used in work of the optical processors. The modern laser technique allows to realize the various regimes of excitation of the photon echoes' diversity. Now the experiments are transfered to the femtosecond diapason of durations. It permits to make the investigation of ultrafast processes in condensed media at room temperature. The special attention is paid to phenomenon of the long-lived stimulated photon echo (LSPE), since just one possesses by perspectives of use in work of the optical echo-processors. This phenomenon is formed in the three-level system (but not in the two-level system, as the ordinary photon echo), when one level is metastable. The Van-Vleck paramagnetic crystals doped by rare-earth ions (such as Pr3+, Eu3+, Tb3+, Tm3+ and Ho3+) are used as information medium. As a rule, the experiments are carried out at the liquid helium temperatures, when the life time of the metastable level may achieve few hours. As a matter of fact, this time is one of optical phase memory and the time interval between the second and readout pulses may be changed from few ms to few hours. The physical principles of the optimal function of the optical processors based on LSPE are analysed in details. The special attention is paid to the multipulsed and multichannel regimes. Scheme of one-position optical memory device, realized in Kazan Phys.-Tech. Institute of RAS, is discussed. The principles of the echo holography (including the color one) are analysed and the ways of its using in the echo-processor's function are considered. The investigations devoted to creation of the echo-processor, based on the Hopfield-Little model of the cell computer, are also discussed.

1.54 J. Sajeev

Quantum and Nonlinear Optics in a Photonic Band Gap

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Photonic band gap (PBG) materials are a new class of dielectric materials which exhibit a complete three-dimensional gap to electromagnetic wave propagation. These materials facilitate two novel and fundamental optical principles, namely (i) the coherent localization of light and (ii) the control and inhibition of spontaneous emission of light from atoms and molecules. The simultaneous realization of these two effects leads to a variety of theoretical predictions for novel quantum and nonlinear optical effects involving photons and atoms within a PBG. These include photon-atom bound states, non-Markovian band edge lasing effects, low threshold collective atomic switching, and coherently controlled, phase sensitive single-atom optical memory. I review these effects, their possible experimental realization, as well recent progress in the microfabrication of 3-d PBG materials on the optical scale using self-assembly methods.

1.55 R. Sauerbrey

Long Range Propagation of Terawatt Laser Pulses in the Earth Atmosphere

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When intense TW-fs-laser pulses propagate in the atmosphere, nonlinear selffocusing effects cause the intense laser beams to disintegrate into several filaments. Selffocusing ceases and stable filaments are formed when an equilibrium is achieved between diffraction, selffocusing and ionization [1,2]. We investigated the conductivity of the filaments and started experiments on an application of the white light continuum generated by these pulses as a source for LIDAR measurements [3,4]. The freely propagating laser pulses start to produce a white light continuum in air that can be used for a new and convenient LIDAR (Light Detection and Ranging) application. Combining the advantages of both conventional LIDAR and long path absorption techniques, this application has the potential to detect simultaneously different species of air constituents and to give complete information of freely chosen air columns, like temperature, water content or pollutants. If the whole unit of laser and detection apparatus can be made mobile, it represents a very powerful tool as a fast scanning atmospheric detection system. Very weak absorption lines of oxygen and water have been measured demonstrating the usefulness of the system for atmospheric investigation. When the laser beam is slightly focused, there is a certain threshold for the generation of light channels. These channels display beautiful colors, but they also could have technological functions in lightning prevention. For the idea of using such channels as lightning rods, it is very important to know the electron density. We examined the conductivity of these channels and found a lower limit for the electron density of , sufficient for the initiation of atmospheric discharges.

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1.56 W. C. Schieve

Detection statistics in the Micromaser

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We present a general theory for the calculation of various statistical quantities describing the detection of a beam of atoms emerging from a micromaser. Comments are made on the use of non-normalized conditioned density operators for the dynamics between detection events. Detection statistics are examined for the standard micromaser setup in which the excitation levels of the emerging atoms are measured. The mean time between detections and the mean number of successive detections of the same type are evaluated for various detector efficiencies ranging from 100% to 50%. The method used works for unequal detector efficiencies.

1.57 M. Scalora

Laminated Photonic Band Structures with High Conductivity and High Transparency: Metals Under a New light

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We have developed a new transparent conductor based on one-dimensional metal-dielectric photonic band gap structures. Thin-film metal-dielectric filters containing at least 150nm of silver have been fabricated, with transmittance greater than 50% over the 500-600nm waveband, and sheet resistance of ≈ 0.1 Ohm/Square. Theoretical calculations predict 25% transparency levels for structures that contain $1/2$ μm of silver, and transparencies that approach 80% for structures that have in excess of 100 nm of silver. Some applications for transparent, conducting films include antennas embedded in windshields, electrodes on flat panel displays, electromagnetic shielding, and solar window panes, to name a few.

1.58 W. P. Schleich

Quantum carpets and vortices in Bose-Einstein condensates

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Highly regular spatio-temporal or multi-dimensional patterns in the quantum mechanical probability or classical field intensity distributions can appear due to pair interference between individual eigen-modes of the system forming the so-called intermode traces. These patterns are strongly pronounced if the intermode traces are multi-degenerate. This phenomenon occurs in many areas of wave physics. We briefly review the concept of quantum carpets and then concentrate on the applications to Bose-Einstein condensates.
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1.59 A. V. Sergienko

Spatial Entanglement and Quantum Interferometry

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A pair of photons (two-photon state) generated in the nonlinear process of spontaneous parametric down conversion (SPDC) is strongly correlated in time (energy), space (momentum), and polarization (angular momentum). We experimentally demonstrated a new approach to the detection and the analysis of two-photon spatial correlation. The use of a single-photon-sensitive CCD camera allows us to have a permanent record of the two-photon realization which permit subsequent evaluation of the spatial correlation. The observation of strong momentum correlation (over the k-vector directions in space) results in interesting spatial interference and quantum imaging effects when the two-photons, which are well-separated in space, are treated as a single quantum entity. This feature has important implications for the development of novel quantum imaging techniques. This effect can also improve the remote transfer of two-dimensional analog image information with a high degree of security. We consider potential implications of this effect in the field of entangled microscopy.

1.60 R. N. Shakhmuratov

Dark state in ruby: analysis of the feasibility

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The possibility of population trapping in a nonabsorbing state under the excitation of the R_1-line in ruby is considered. This trapping may occur when a resonant transition is split in two paths due to the level mixing effect. The latter takes place when a magnetic field H, applied parallel to the c_3-axis, has a value H=2.07 kOe or H=4.14 kOe. At the former value the ground state spin sublevels +3/2 and -1/2 cross, whereas at the latter the spin sublevels +1/2 and +3/2 cross. Small misalignment of the magnetic field with respect to the c_3-axis creates the state mixing. Then, for example, at the second crossing a π-polarized laser beam inducing the transition $+1/2(^4A_2) \rightarrow +1/2(\overline{E})$ can excite two transitions simultaneously, i.e. the transition starting from the state +1/2 with different admixtures of the state +3/2. There are two such states, $\Psi_\pm = (|+1/2\rangle \pm |+3/2\rangle)/\sqrt{2}$, differing by the sign of the state +3/2 admixture. Because of the transition split in two paths (Raman-like excitation) the laser beam creates the coherence of states Ψ_+ and Ψ_-. There is one particular coherent state $(\Psi_+ - \Psi_-)/\sqrt{2}$ which can not be excited by the π-polarized beam because of the selection rule. This is the dark state. Excitation of the other combinations of the states Ψ_+ and Ψ_- is possible. Spontaneous emission populates all the states, including the dark state as the direction of the spontaneous emission is not defined. If the life time of the excited state is much shorter than the life time of this particular (dark) state, then two step process of laser excitation and spontaneous emission will depopulate all the states except the dark one. At high Rabi frequency of the laser pump we expect to achieve lengthening of the spin coherence T_2 up to T_1=300 msec which was observed in ruby at the microwave excitation of the ground state spin [1]. This is reasonable since a two-quantum excitation of the spin transition is quite similar to the direct resonant excitation by microwave power. Therefore we expect to achieve a significant population of the dark state and, as a result, a spontaneous emission decrease at the R_1-line excitation when level crossing takes place. By our estimation this decrease will be about T_1/T_{1opt}=100 where T_{1opt}=3 msec, the life time of the optically excited state.

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1.61 V. M. Shalaev

Fractals in Microcavities: New Feasibilities for Laser Physics and Photonics

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A novel class of optical materials, microcavities doped with nanostructured fractal aggregates, is shown to possess unique properties with high potential for application in laser physics, optoelectronics, and photonics. Fractal aggregate optical excitations may be localized in regions significantly smaller than the wavelength so that the corresponding electromagnetic energy becomes concentrated in regions smaller than the diffraction limit of conventional optics, resulting in large local fields. Seeding the aggregates into microcavities further increases the local fields because of light trapping by microcavity resonance modes. These microcomposites possess unique optical characteristics, including extremely large linear and nonlinear susceptibilities. In our experiments, lasing at extremely low pump intensities, below 1 mW, and dramatically enhanced Raman scattering was observed in microcavity/fractal composites.

1.62 A. S. Shumovsky

Stokes parameters and operators

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It is well known that the polarization measurements take very important part in optics and spectroscopy. Remarkable recent developments in the field of quantum optics have given rise to a new application of polarization measurements in the quantum entanglement research and thus in the quantum information processing. For these purposes, it is necessary to know how the polarization behaves in the quantum domain where it is determined to be a given spin state of the photons.

It is shown that the description of polarization based on quantization of classical Stokes parameters is incomplete in quantum domain. For example, the polarization of the electric dipole radiation of the atomic or molecular transitions is described by nine generators of the $SU(3)$ sub-algebra in the Weyl-Heisenberg algebra of photons, in other words, by nine independent Stokes operators instead of four dependent classical Stokes parameters. Although some of the Stokes operators have one and the same averages, they describe absolutely different physical quantities with strongly different quantum fluctuations. The quantum polarization properties of the electric dipole and quadrupole radiation are examined as a function of distance for the near, intermediate, and far zones. Application of results in the near-field optics and quantum entanglement research is discussed.

1.63 S. Szabo, poster

Phase optimized states via coherent-state superpositions

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Phase optimized states of light have been widely examined in the literature [1-3]. In these states the phase noise is minimal for a given mean photon number that can be advantageous in practical applications. In previous papers it was shown that several quantum states can be represented by one-dimensional continuous coherent state superpositions [4-6]. Furthermore it was also shown that discrete coherent state superpositions with optimally chosen parameters based on the one-dimensional continuous representation can approximate a quantum state at high precision [7]. This discrete coherent state representation is useful not only for simplifying analitical calculations but it can serve as a basis for experimental realisation.

In this paper we find the one-dimensional coherent state representation of the phase optimized states. Using this representation we obtain discrete coherent state superpositions with optimized parameters approximating these states. We show that even a very small number of coherent states is enough to achieve high precision which is useful for experimental realisation.

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1.64 E. A. Vinogradov

Electron injection dynamics through the Schottky barrier

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Dynamics of optical reflection spectra of the Schottky barrier structures based on semiconductor (ZnS, ZnSe) film on thick metal (Ni, Cr, Cu) film on quartz substrate were investigated by femtosecond pump-supercontinuum probe spectroscopy in wide spectral region 1.6 - 3.2 eV. For the pumping energy below the energy gap of semiconductor the laser pulse excites mainly electrons of a metal (i.e. the boundary of the microcavity). Nonequilibrium carriers of the metal penetrate through the Schottky electron barrier into the semiconductor and change the dielectric function of the semiconductor microcavity and the boundary conditions forming instant electric dipoles on the boundary. Photoinduced changes in optical thickness of the microcavity and in the boundary condition lead to observable in femtosecond time scale shifts of cavity modes. Ultrafast processes connected with this stage are analyzed. Applications for Ultrafast optical switching are discussed.

1.65 G. R. Welch

Slow Light and Hot Atoms

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A striking illustration of quantum coherence effects is the extreme reduction of group velocity of light beams propagating in dense coherent media. This reduction arises from the enormous positive dispersion exhibited by media displaying electromagnetically induced transparency (EIT). Previous direct and indirect measurements of increasingly low group velocities in coherently prepared media have ranged from c/165 in early experiments of Harris et al. to c/20,000,000 in a recent experiment by Hau et al. conducted in a Bose-Einstein condensate.

We report that very large group delay (slow group velocity) of light can be observed in a cell of hot (360 K) ^{87}Rb atoms. This relatively easily created medium also displays very strong nonlinear coupling between very weak optical fields. In particular, we see group delay (T_g) of 0.26 ms for propagation through our 2.5 cm rubidium cell. We have also observed extremely efficient nonlinear interactions, such as generation of new laser frequencies.

The slow group velocity and efficient nonlinear processes are closely related, that is, T_g is a crucial factor in various linear and nonlinear optical processes using EIT. The unusual properties of dense coherent media furnish new regimes of high precision spectroscopy and allow nonlinear interactions of very weak light fields.

1.66 E. Wintner

Diode-pumped ultrashort pulse solid-state lasers

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Femtosecond laser pulses can be produced very efficiently by diode-pumped solid-state lasers containing transition or rare earth ion doped host media. Rather compact laser setups of moderate costs can be realized of simple, robust, and stable design allowing useful specifications with respect to pulse duration, wavelength, average power, repetition rate and last but not least pulse quality and stability. With this background it is nowadays justified to speak about "real world" diode-pumped solid-state lasers for ultrashort pulses.

Such ultrashort pulses, i.e. picosecond and femtosecond pulses, are very useful for many applications, which may be divided into two groups, time-resolving spectroscopic measurements and investigation of nonlinear interaction processes. Applying shortest pulses following well-known schemes sub-fs time resolution has been achieved since a few years. In case of predominant nonlinear interactions, ultrashort pulses allow to avoid extreme heating and consecutive thermal destruction of material while taking advantage of the high electromagnetic fields yielding interesting new reversible and nonreversible nonlinear effects as well as widely useful nonthermal ablation of material. The latter one opens a new avenue for even commercial use of powerful femtosecond laser radiation.

1.67 K. Wodkiewicz

Fractional Dynamics of the wave packets in phase space

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The dynamics of atomic wave packets is discussed in terms of the Wigner function and analogous phase space distributions. In this context various wave effects like the fractional Talbot effect or the fractional Fourier transform will be formulated in phase space with the help of the Wigner function. We discuss a one dimensional diffraction of an atomic wave packet from a periodic grating using the phase space formalism. Using the phase space formalism a compact summation formula for the Wigner function at rational multiples of the Talbot distance is derived. The summation formula shows

that the fractional Talbot image in the phase space is generated by a finite sum of spatially displaced Wigner functions of the source field. We show that the whole propagation of the field is encoded in the interference terms of the Wigner function, generated by coherence between Fourier components of the source wave. The variety of the Fresnel images is simply a result of a complicated interplay between phases of these interference terms. A summation formula is derived that demonstrates that the fractional Talbot effect can be also understood as an interference between components shifted in the position space by fractions of the pattern period. Using standard optical methods for wave packets, we shall derive the positive Q-representation and show its relation to the interference effects. A close analogy between the fractional effects and the dynamics of various nonlinear quantum systems will be provided.

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1.68 V. I. Yukalov

Excited Coherent Modes of Ultracold Trapped Atoms

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The possibility of creating a Bose condensate of ultracold trapped atoms in a non-ground-state is suggested. Such a nonequilibrium Bose condensate can be formed if one first obtains the conventional Bose condensate in the ground state and then transfers the condensed atoms to a non-ground-state by means of a resonance pumping. The properties of ground and non-ground-states are compared and plausible applications of such nonequilibrium condensates are discussed. In particular, it can be used for forming excited coherent modes of atom lasers.

1.69 V. I. Yukalov

Formation of directed beams from atom lasers

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Dynamics of spin–polarized neutral atoms and molecules, in magnetic fields typical of quadrupol magnetic traps, is studied. A new regime of motion is found where particles move mainly in one direction forming a well–collimated beam. This regime suggests a mechanism for creating directed coherent beams of neutral atoms from atom lasers.

1.70 A. A. Zadernovsky

Ignition of burst two-quantum generation of coherent gamma-photons

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External ignition of two-quantum induced gamma-emission of free excited nuclei or positronium atoms by counterpropagating photon beams is considered. The performed analysis reveals the following main advantages and shortcomings of the method of external ignition:

Dynamic distributed feedback of a special type inherent only in two-quantum stimulated emission in counterpropagating photon beams is established in the absence of any reflecting structures.

When the activity parameter of a medium and the intensities of igniting photon beams achieve critical values, the nonlinearity of the feedback gives rise to an avalanche-like release of nuclei excitation energy or annihilation of positronium atoms accompanied by the emission of a giant pulse of coherent gamma quanta.

In contrast to single-quantum emission of free nuclei with Doppler-broadened gain line, two-quantum induced gamma-emission caused by counterpropagating igniting photon beams involves all nuclei in the emission process regardless of their individual velocities.

Spontaneous photons emitted in each event of spontaneousstimulated radiative annihilation of positronium atoms induced by the first igniting beam alone are perfect partners for subsequent two-quantum stimulatedstimulated annihilation and can play the role of the second igniting beam. The ignition of avalanche-like induced annihilation by a single photon beam requires intensities an order of magnitude higher than those necessary for the ignition in two identical counterpropagating photon beams.

Ignition with a single photon beam offers certain advantages associated with a relativistic motion of positronium atoms, which allows one to substantially reduce the requirements to a source of backward igniting photons.

At present, the implementation of such a processes is impeded by the lack of sources of igniting gamma quanta with sufficient intensity and sufficient pulse duration. Apparently, one can make use of the advantages of external ignition only in the final stage of a source of gamma quanta (for example a gamma-ray laser, a relativistic undulator, a free electron laser, etc.) for producing a short pulses of gamma photons with high peak power.

1.71 J. M. Zavada

Optical properties and novel applications of rare earth-doped III-nitride semiconductors

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Rare earth doped semiconductors have been studied for more than a decade because of the possibility of developing compact electroluminescence (EL) light sources and optical amplifiers. Trivalent erbium ions (Er3+) and praesodymium ions (Pr3+) are of special interest because they exhibit an atomic-like transitions at 1540 nm and 1300 nm, respectively, which correspond to the primary propagation wavelengths of silica-based optical fiber communication networks. While EL devices, based on Er-doped Si and GaAs materials, have been fabricated, their efficiency remains too low for practical applications. Several years ago, an important observation was made that there was less detrimental temperature quenching of the Er3+ PL intensity for larger bandgap host materials. Therefore, rare earth doping of wide gap semiconductors appears to be a promising approach to overcome the strong thermal quenching of luminescence found in Si and GaAs. In particular, GaN epilayers doped with Er ions have shown a highly reduced thermal quenching of the Er luminescence intensity from cryogenic to above room temperatures. In this talk, recent data concerning the luminescence characteristics of Er-doped, and Pr-doped, III-N thin films will be presented. Two principal methods have been successfully used for incorporation and optical activation of the rare earth ions in the III-N films: ion implantation and in-situ doping during epitaxial growth. Considerably different emission spectra, with different thermal quenching characteristics, have been measured depending upon the incorporation technique and the wavelength of the optical pump. Rare earth doping of III-N thin films can lead to a variety of novel electrical and optical devices. GaN thin films, doped with either Er or Pr, have been processed into light emitting diodes, resulting in visible and infrared emissions. Microdisk laser structures have also been fabricated through dry etching techniques. Two photon excitation of a thin film doped with rare earth ions can lead to two-dimensional displays. Focused ion beam implantation can produce arrays of localized regions of rare earth ions that can be used in high density optical storage devices. Data concerning the optical properties of prototype devices will be presented and concepts for future applications will be discussed.

1.72 S. Y. Zhu

Spontaneous emission in three-dimensional photonic crystals

Shi-Yao Zhu

The spontaneous emission from a two-level atom in three-dimensional photonic crystals is quite different from that in one dimensional photonic crystals. When the upper level of the atom is moved from within the gap to in the band, the emitted radiation changes from localized field to diffusion field, and then to proporgating field.

The amplitude of the radiation at a certain point in space keeps constant (localized field), decays in a power law (diffusion field), and decays exponentially (proporgating field). There are two characteristic frequencies, which are both in the band, to separate the three different fields. There is some population in the upper level, if the radiation is the localized one. There is no population in it, if the radiation is a diffusion or proporgating field.

2 Strong–field phenomena

2.1 A. I. Andriushin

Orientation of molecules in a strong laser field

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The problem of the field-induced orientation of molecules is solved is solved in the framework of a model which takes into account Λ-type transitions (via the first unstable electronic state) between rotational levels of the ground vibrational/electronic molecular state. In the set of equations for the corresponding probability amplitudes interaction with a light field is characterized by the polarizability tensors $\alpha_{N,N'}$ and tensor of dissociation width $\Gamma_{N,N'}$, where N is the molecular rotational quantum number. The effect of orientation in a strong field is shown to be well pronounced only if $\alpha_{N,N'} \gg \Gamma_{N,N'}$. The strong-field criterion is given by $\alpha_{N,N'} \gg B$, where B is the rotational constant. The initial-value problem is solved for a pulse with the Gaussian field-strength envelope $\varepsilon_0(t)$. In the case of a pulse longer than the rotational time $\tau \gg 1/B$, the calculated average angle between $\overline{\theta(t)}$ molecular axes and the light polarization vector ε_0 is shown to follow adiabatically the pulse envelope $\varepsilon_0(t)$ and to have a deep minimum at $t = 0$, when the field strength has its maximum. This is a clear manifestation of a dynamical field-induced orientation of molecules. Angular distribution of molecular fragments arising via photodissociation is studied and its relationship with the above-described orientation of molecules is investigated. Two mechanisms giving rise to such an effect are discussed and compared with each other: (a) narrowing of angular distribution of photodissociation products due to features of multiphoton transition to the unstable electronic state and (b) narrow angular distribution of photodissociation products as a consequence and replica of the preliminary field-induced orientation of molecules before their dissociation. In the case of a strong field ($\alpha_{N,N'} \gg B$), the mechanisms (a) and (b) are shown to work at short ($\tau \ll 1/B$) and long ($\tau \gg 1/B$) pulse duration, respectively.

2.2 A. Bandrauk

Phase Control of Ionization of Molecules at High Laser Intensities

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Numerical solutions, of the dependent Schrödinger equation for one electron, H_2^+, H_3^{++} and two electron systems H_2, H_3^+ have been obtained for ionization with two pulses of the form $E(t) = E_0(t)(cos\omega t + \gamma cos(2\omega t + \phi))$ for intensities $I_0 = 10^{14} W/cm^2$. It is found that optimum phase control of the ionization process occurs for the laser parameters $\gamma = 0.5$ and $\phi = 0$ at the critical distance R_c where Charge Resonance Enhanced Ionization, CREI is the dominant mechanism discussed earlier (Bandrauk *et al.*, Phys. Rev. **a48**, 3837 (1993); **A52**, 2511 (1995); J. Phys. **B28**, L723 (1995)). A recent complete exact non Born-Oppenheimer simulation method for dissociative ionization of H_2^+ (Phys Rev. **A57**, 1176 (1998)) is used to study the phase dependence of ATI and Coulomb Explosion. Comparison will be made with current experiments and applications to selective photofragmentation of molecules at high intensities will be discussed. The most important conclusion is that selectivity is optimum at the CREI critical Configurations of molecules.

2.3 D. Bauer

Stabilization of two-electron systems in intense laser fields

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The advent of high intensity lasers led to an increasing interest in non-perturbative studies of atomic systems interacting with intense laser light. One of the most frequently revisited topics during the last fifteen years was *stabilization* of atoms (or ions) against ionization in intense laser light, i.e., for increasing laser intensity the ionization rate *decreases* [1]. Unfortunately, there are not yet high intensity lasers available delivering sufficiently energetic photons to stabilize directly from the ground state. Therefore most of the studies in this field are of analytical or numerical nature (see [2,3], and references therein).

In our contribution we study numerically stabilization against ionization of two-electron atoms in an intense laser pulse. For a low-dimensional model atom we are able to calculate the fully correlated, exact wavefunction which we compare with results from simpler, approximate models. We concentrate on two frequency regimes: very high frequency, where the photon energy exceeds both, the ionization potential of the outer *and* the inner electron, and an intermediate frequency where, from a "single active electron"-point of view the outer electron is expected to stabilize but the inner one is not. Our results reveal that correlation reduces stabilization when compared to results from single active electron-calculations. However, in the high-frequency case we observe stabilization [4]. We will also present results for "real" Helium. In this case it is, with current days computers, not possible to solve directly the time-dependent Schrödinger equation with the necessary accuracy, including the full electron correlation term. However, from our experiences with the two-electron model atom we can estimate which approximations are reasonable to apply [5].

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2.4 J. Bauer

Classical simulations for atoms and molecules in intense laser fields

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We use molecular-dynamics simulation to study the ionization and dissociation in a one-dimensional model of multielectron atoms and molecules exposed to strong laser fields. We show that one can qualitatively well recover the experimental appearance intensities for different charge states of multielectron noble gases. For molecules we investigate the kinetic energy defect in the process of Coulomb explosion.

2.5 A. Becker

Multiple ionization processes in noble gas atoms in femtosecond laser pulses

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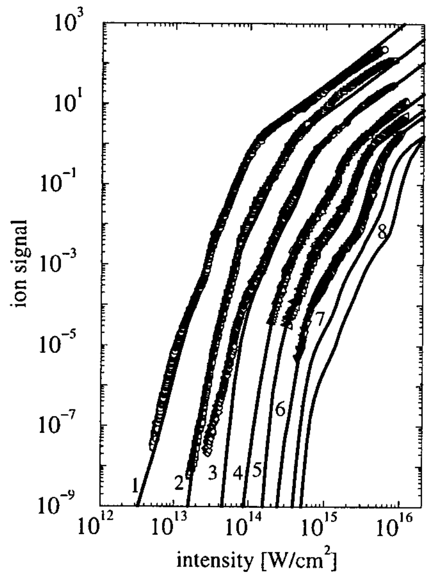

Recent experiments on double and multiple ionization of noble gas atoms in intense laser fields (e.g. [1,2]) have revealed unusually large probabilities, which violate the expectations based on the sequential (or step-wise) mechanism that was used to interpret the older data. They are often also characterised by one or more knee-like structures in their intensity dependence. We discuss theoretical insights gained recently [3-6] in understanding the results in terms of a non-sequential mechanism of double and multiple ionization of a complex atom, that is dominated by electron correlation. A non-sequential ionization model is developed to analyze the intensity dependence of the laser induced double and multiple ionization yields. Predictions of the present theoretical model for the ion yields at different optical and VUV wavelengths are found to be in good agreement with the experimental results for all charge states measured and over the entire intensity range. In the Figure we present the results of calculations (solid curves) for the n-fold ionizations for n = 1–8 [4-6], and compare them with the experimental ion yields from Xe measured at λ = 800 nm by Larochelle et al. [2]. The data can be seen to agree remarkably well with the calculations and, moreover, a weak structure in the case of Xe^{2+} and a number of relatively weak knee-like structures for the higher charge states are also reproduced by the calculations. Further analyses show significant presence of non-sequential (or direct) escapes of upto four electrons in the experimental data.

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2.6 W. Becker

Above-Threshold Ionization for Elliptical Polarization

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Elliptical polarization of the driving laser field enlarges the parameter space of above-threshold ionization (ATI) by the ellipticity as an additional parameter. Moreover, it destroys the cylindrical symmetry of the spectrum and leaves only inversion symmetry intact. We will show angle-resolved ATI spectra for various rare gases, taken for a dye laser (630 nm, FWHM duration of about 50 fs, $I \sim 10^{14}$ W/cm^2) for various ellipticities, for electron energies up to about $15\,U_p$ which is much higher than the classical cutoff at $10\,U_p$ for linear polarization (U_p denotes the ponderomotive potential). The spectra display several qualitative features which are present in all of the rare gases investigated. In the rescattering regime, most notably for xenon, the presence of two maxima in the angular distributions is particularly conspicuous. It persists up to the highest orders that can be detected. We model the high-order spectra by a generalized KFR approach and evaluate it employing a zero-range binding potential. In certain situations, the double-maximum structure is reproduced. For intensities of about 10^{15} W/cm^2 (higher than in the experimental data) the spectra exhibit the characteristic structure which is caused by alternating constructive and destructive interference of Lewenstein trajectories. In this regime, classical (simpleman) modeling yields the envelope of the calculated spectrum to a very good approximation.

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2.7 S. Bivona

Photoelectron current modulation in multiphoton detachment of H^-

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Recently, we have carried out calculations of cross sections of photodetachment of a negative ion irradiated simultaneously by a weak, photodetaching, electromagnetic field of frequency w_{H1} and an intense low-frequency bichromatic field (LF), when their frequencies w_{l1} and w_{l2} field are commensurate. It has been found that when $w_{l2} = 2w_{l1}$ and the relative phase of the LF fields is $p/2$, the photoelectron spectra show a very pronounced maximum when the ejected electron absorbs by the LF field such an amount of energy almost equal to the ponderomotive shift provided by the bichromatic field. In this communication an explanation of the location of the maximum of the photoelectron current is given, and the analysis is extended to the case in which different ratios of w_{l2}/w_{l1} are considered. Further, the possibility of quantum control of the photoelectron current by the addition of an extra low-intense detaching field of such a frequency w_{H2} that $w_{H2} - w_{H1}$ is equal to an integer multiple of w_{l1} is discussed. It is found that by changing the relative phase d of the two photodetaching weak fields, the photoelectron current can be strongly modulated by the action of the bichromatic field, and that such a modulation depends in a very simple way on d.

2.8 B. Carré

Spatial and temporal coherence of high-order harmonics

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High-order harmonic generation provides an efficient source of radiation in the extreme ultraviolet (XUV) region, with rather unique characteristics. The most remarkable are the very short pulse duration, and the spatial and temporal coherence. We report studies which involve the spatial and temporal coherence of harmonics produced with a 60 fs, 800 nm Ti:Sapphire laser in Saclay. For spatial coherence, we first measure the beam quality factor M^2 of the 13^{th} and 15^{th} harmonic beam, by analyzing the spot size at the focus of a spherical multilayer mirror [1]. We obtain M^2 number close to 2, which means that a tight focussing can be achieved. Second, we measure the degree of spatial coherence in an interferometric experiment using Fresnel's mirrors, similar to that by Ditmire et al using Young's two-slit [2]. We probe the spatial coherence in the beam, between pairs of points distant of a given d in the transverse section. A relatively high degree of coherence, $\gamma \geq 0.5$, is measured throughout most

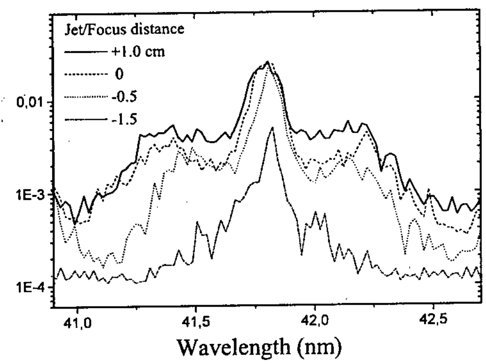

Figure 1: (a): Spectral profiles of the 19^{th} harmonic in Ne for different gas jet/laser focus relative positions

of the beam section, which corresponds to coherence length d_{coh} significantly larger than those previously reported.

For studying the temporal coherence, we have measured the spectral profiles of high harmonics as a function of different parameters. They exhibit noticeable variation in both shape and width, e.g. in fig.1 for H19 in neon, as a function of gas jet/laser focus position. The change with focusing can be related to a phase modulation of the harmonic emission following the intensity-dependent phase of the atomic dipole [3].

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2.9 V. E. Chernov, poster

X-laser induced nuclear decay: Resonance internal conversion

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The behaviour of nuclei in intense electromagnetic field is a subject of great theoretical interest. Considerable changes in these processes (e. g. in internal conversion) could be achieved by resonance interaction between nuclei and their electronic shells, when the correspondent nuclear and electronic levels are sufficiently close and the defect of resonance is compensated by laser radiation. As an example of such processes,

the laser induced discrete internal conversion (LIDIC) in metastable nuclei ^{235m}U [1], ^{229m}Th [2], and ^{99m}Tc [3,4] can be considered.

The K- and L- conversion in ^{99m}Tc is forbidden by the energy conservation law, and the M-conversion is the main channel of the metastable level decay. However, the L-conversion becomes possible if a $\sim 500\,\mathrm{eV}$ photon is absorbed from an external radiation [3]. In the work [4] we considered a highly-stripped Tc ions, where the same process would require the photon energy of a few eV. The obtained numerical estimations show that the laser radiation of a comparatively low intensity $I \sim 10^7\,\mathrm{W\,cm^{-2}}$ can double the activity of $^{99}Tc^{32+}$ ions.

We also note another interesting property of ^{99}Tc: it has a short-lived nuclear level lying below the metastable one. So the coherent γ-radiation due to $7/2^+ \to 9/2^+$ nuclear transition could be realized when the incident radiation intensity is sufficiently high. Our numerical estimations for a coherent single-pass amplification yield $I \sim 10^{22}\,\mathrm{W\,cm^{-2}}$.

In the present work we show that the above mentioned isomers are not unique objects for LIDIC process; the resonance conditions can also be satisfied, e.g., for ^{105}Ag, ^{189}Os, ^{191}Os, ^{191}Au, ^{193}Ir, ^{205}Pb in rather wide spectral range of the external radiation — from soft VUV up to X-Ray. We provide some estimations for the characteristic radiation frequencies for these isomers.

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2.10 S. L. Chin

Inner shell electron ejection and fluorescence during tunnel ionization and fragmentation of molecules using intense femtosecond Ti-sapphire laser pulses

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Using 200 fs linearly polarized Ti-sapphire laser pulses, we studied the tunnel ionization and fragmentation of C_2H_4 molecules through the measurement of ions and photons. In the case of tunnel ionization, the PPT model advanced by us recently can explain the ion signals nicely. In particular, by developing a new model which considers the fragmentation of the molecule as resulting from the tunnel ionization of inner shell

electrons, we were able to predict correctly the abundance of $C_2H_3^+$ and $C_2H_2^+$. This inner shell electron ionization is confirmed by the observation of collisionless radiation from CH radicals.

2.11 A. Cionga

Free-free transitions in electron-hydrogen: Second order field-induced corrections to the elastic line

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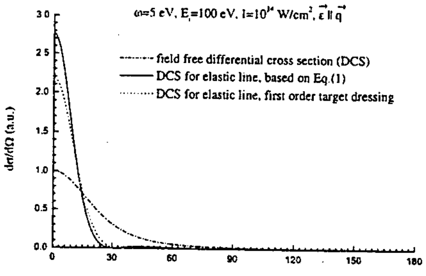
In the domain of moderate field intensities the hybrid treatment introduced by Byron and Joachain [1] was frequently used to study laser-assisted electron-atom collisions [2].

It is the aim of this work to investigate field induced corrections to the elastic line, for which the net number of photons exchanged between the colliding system and the field is zero. We describe the target in the field using second order perturbation theory: this leads to a transition matrix element that contains first and second order dressing terms:

$$T_0 = J_0(\vec{q}\cdot\vec{\alpha}_0)\left[\mathcal{M}_{el}(q) + \alpha_0^2\omega^2\widetilde{\mathcal{M}}_{at}^{(II)}\right] - \alpha_0\omega J_0'(\vec{q}\cdot\vec{\alpha}_0)\mathcal{M}_{at}^{(I)} + \alpha_0^2\omega^2 J_0''(\vec{q}\cdot\vec{\alpha}_0)\mathcal{M}_{at}^{(II)}. \quad (1)$$

J_0 and J_0' (J_0'') are zero order Bessel functions and their first (second) derivatives, $\vec{\alpha}_0$ describe the quiver motion and $\mathcal{M}_{el}$ denotes the matrix element of the form factor operator. $\mathcal{M}_{at}^{(I)}$, $\mathcal{M}_{at}^{(II)}$, and $\widetilde{\mathcal{M}}_{at}^{(II)}$ are connected to first- and second-order target dressing; they depend not only on the momentum transfer $\vec{q}$, but also on the frequency, ω, and the polarization, $\vec{\varepsilon}$, of the field.



The influence of target dressing on the sum rule was first discussed by Beilin and Zon [3] in the framework of the closure approximation. The validity of that formula is discussed using the analytic low frequency limit of the dressing terms that we have obtained.

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2.12 L. F. DiMauro, plenary

Strong Field Interactions in the Tunneling Regime

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Over the past few years, strong-field physics has advanced to a state that quantitative tests of theoretical models are now possible experimentally. This is particularly important to identify the universality of all strong-field effects, such as above-threshold ionization (ATI), high optical harmonic generation (OHG), and multiple ionization. This recent advance in understanding is intimately tied to the progress in the development of high powered, kilohertz repetition rate lasers and powerful numerical techniques. Furthermore, a simple quasi-classical model based on the rescattering of a laser-driven tunneled electron with its parent ionic core has resulted in some revealing insights into the underlying dynamics. In this talk, a comprehensive review of laser-atom interaction will be discussed along with future challenges.

2.13 F. Ehlotzky

Asymmetry, angular and polarization effects in relativistic free-free transitions in a powerful laser field

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We consider potential scattering of electrons in a powerful laser field. To a first order of approximation the laser-dressed electron is described by the solution of the Klein-Gordon equation in a linearly polarized plane wave field. It is shown that the differential cross sections of free-free transitions are asymmetric with respect to the direction of propagation of the radiation field. This asymmetry has its origin in the laser-induced drift motion of the electron. Numerical calculations also indicate the existence of broad dark angular windows, i. e. scattering angles for which the nonlinear cross sections are marginal. We also show that at nearly relativistic scattering conditions, in which the space-dependence of the laser field cannot be ignored, characteristic angular and polarization effects can be encountered for specific scattering configurations. These will not show up in the non-relativistic case where the radiation field is treated in the dipole approximation. We moreover demonstrate that even for laser field intensities, at which non-relativistic calculations should apply, one can observe discrepancies between relativistic and non-relativistic results.

2.14 M. A. Efremov

Quantum and classical versions of the Kapitza-Dirac effect and scattering of wave packets

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At present electron wave packets of a size comparable with an optical wave length ($\lambda \sim 10^{-4}cm$) can be created in a controllable way in the process of multiphoton ionization of atoms. Fruitfulness of such an approach was demonstrated in the famous experiment by Bucksbaum et al. [1], where electron wave packets were created via ionization of atoms by the first laser and their scattering at the focus of the second laser was investigated.

It may be even more interesting to use such wave packets for investigation of their scattering by a standing light wave. This effect [2] is pretty well studied both theoretically [3-5] and experimentally [6]. However, even in this widely studied area there remains an interesting manifold of problems, which were not considered earlier and which concern similarity and difference between the results of quantum-mechanical and classical considerations and dependence of the results on the incident electron state: a plane wave or a wide/narrow wave packet. We compare two formulations: scattering of a quantum-mechanical electron plane wave and scattering of a beam of classical particles by a classical light standing wave. The results coincide or not in dependence on the value of the parameter $\beta = mc^2/\hbar\omega^2\tau$. The case $\beta \gg 1$ corresponds to the classical limit of the quantum theory in which the results of the two formulations coincide. The opposite case, $\beta \ll 1$, is the case of Bragg scattering in the quantum theory, and under these conditions the results predicted by the two outlined formulations are strongly different. Specifically, the average angle of scattering and the distribution function of scattered electrons are calculated, and, under the condition $\beta \ll 1$, they are shown to be strongly different in the case of the two formulations discussed. However, the difference disappears if the initial state of an incident electron is taken in the form of a sufficiently narrow wave packet, rather than a plane wave. Hence, an experimental measurement of the average angle of scattering or of the distribution function of electrons scattered by a standing light wave can be used as a detector of a size of the wave packet characterizing electrons in an incident beam.

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2.15 U. Eichmann

Collective Multi-Electron Tunneling Ionization

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Collective multi-electron tunneling is a fundamental quantum process which seems to have escaped attention in the past. We present the result of a number of experimental and theoretical studies from our laboratory, where a) the collective tunneling process in static fields is theoretically investigated in various approximations, and b) its relevance for non-sequential multiple ionization in strong laser fields is studied.

These efforts were triggered by the discovery of a simple semi-empirical tunneling formula for non-sequential multi-electron ionization in strong laser fields. The formula is able to explain multiple charged ion yields in high-intensity laser experiments over several orders of magnitude of the laser intensity with surprisingly good accuracy, although so far only for linear polarization. The formula has the structure of an one-electron ADK-tunneling formula, with only the binding energy being replaced by the average binding energy E_{eff} which is the total binding energy of the N active electrons, divided by N.

Extensive theoretical studies, including the full numerical solution of the two-particle Schrödinger equation in a spherical approximation, show not only that collective multi-electron tunneling exists as a novel quantum process, but that it proceeds essentially in a highly correlated fashion where the electrons remain at roughly the same radial distance, $r_1 = r_2 = ... = r_N$. Thereby, each electron has to overcome a binding energy equal to E_{eff}, which provides an a posteriori physical basis for the empirical choice mentioned above. The absolute N-electron tunneling rates, however, still come out far too low. The discrepancy may indicate that either the success of the empirical formula is a mere coincidence (although containing the field strength, the number N of electrons and their total binding energy as the only parameters, and holding for practically all existing data on linear polarization), or that there exists an additional correlation in the N-electron tunneling process such that the additional degrees of freedom of the N-1 active electrons are "frozen" in a yet unexplained collective motion. In such a situation the resulting rate for collective N-electron tunneling ionization would fully agree with the empirical one-electron formula.

In order to shed more light on the process, our present and future studies aim at: a) Further exploring the validity range of the empirical formula by investigating experimentally strong field N-electron ionization of atoms over a wide range of total energies and energy partitioning. The focus lies on quasi two-electron systems, including ions and laser excited metal vapor atoms. b) Performing more sophisticated model calculations to investigate quantitatively the novel collective electron tunneling process in static electric fields and possible correlations therein.

2.16 F. H. M. Faisal

Intense Field Ionization of Molecules

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Theoretical analysis of single and double ionization of molecules requires a combined treatment of the non-perturbative field interaction and the many-body problem. A direct simulation approach, that can be carried out for the simple H_2^+ molecular ion, and similar one-electron systems, appears to be practically impossible for systems with more than two electrons, e.g. the multielectron diatomics like N_2 or O_2 and/or more complex systems like C_6H_6. Recently, we have developed a rearranged S-Matrix theory, the so-called Intense-Field Many-Body S-Matrix Theory (IMST) [1], which has been applied very successfully to the analysis of double and multiple ionization of complex atoms [2-5] by femtosecond laser pulses [see, paper by Becker and Faisal, this volume]. In the present work, first, we shall briefly discuss the extension of the IMST to the more complex problem of molecular ionization in intense laser fields [5]. Second, we shall apply the theory to investigate a number of phenomena that occur in molecular interaction with intense lasers: (i) 'enhancement ionization' of a diatomic molecule (H_2), (ii) 'enhancement ionization' of a polyatomic molecule (C_6H_6), (iii) single and double ionization of N_2, (iv) single and double ionization of O_2.
Experimental observation of the single and double ionization of N_2 and O_2 in the fields of intense femtosecond laser pulses have recently been reported [6-8]. They will be compared with the results of the present theoretical calculations. The theoretical results will be discussed with special reference to the role of electron correlation in the double ionization of the molecules and with respect to the role of a fragmentation process that may accompany the ionization process during the field interaction.

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2.17 M. V. Fedorov, poster

Interference vs. transient stabilization of Rydberg atoms in a strong light field

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In the problem of stabilization of Rydberg atoms by a strong light field, two close mechanisms are often mentioned: interference [1] and "transient" [2, 3] stabilization. Sometimes [2, 3], it is assumed that the validity of the concept of interference stabilization restricted by the case of long pulses, $\tau \gg t_K$, where τ is the pulse duration, $t_K = 2\pi n^3$ is the classical Kepler period (in atomic units) and n is the principal quantum number of the initially populated Rydberg level E_n. However, in the theoretical analysis of interference stabilization no limitations of this kind were ever assumed to occur and both cases $\tau \gg t_K$ and $\tau \ll t_K$ were assumed to be well described by this theory. However, in reality some differences between the cases $\tau \gg t_K$ and $\tau \ll t_K$ do occur, and these differences are investigated and described in the talk. Both cases $\tau \gg t_K$ and $\tau \ll t_K$ are investigated on the basis of the same equations for Rydberg probability amplitudes, in which Λ-type transitions via the continuum are taken into account. Investigation is based on a numerical solution of these equations and on the analytical perturbation-theory solution. Interference of the first- and third-order transitions to the continuum is shown to explain an origin of stabilization in both cases $\tau \gg t_K$ and $\tau \ll t_K$. The dependence of the stabilization threshold on the pulse duration is found from numerical calculations and analytical estimates and the threshold field strength $\varepsilon_{thr}(\tau)$ is shown to have a minimum at $\tau \sim t_K$. As a resume, the difference between the cases $\tau \gg t_K$ and $\tau \ll t_K$ is shown to have quantitative rather than qualitative character, and both of these regimes are shown to agree with the concept of interference stabilization. Some other interesting features of the phenomenon are investigated including formation of a pulsating Rydberg wave packet via Λ-type transitions.

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2.18 M. V. Fedorov

Relativistic ponderomotive forces

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Ponderomotive forces, acting upon an electron in an inhomogeneous light field are calculated in the relativistic domain of an incident electron energies. The field is assumed to be weak enough to be considered in the lowest (second) order of perturbation theory. The relativistic Newton equation is averaged over fast oscillations of the field on the electron trajectory. In contrast to the nonrelativistic ponderomotive forces, the relativistic forces are shown to be of a multicomponent character: they consist of a superposition of components directed along (a) field gradient, (b) light polarization vector, and (c) laser axis. The components directed along the polarization vector and laser axis are calculated in their dependence on the angle θ betweeen the initial electron velocity and laser axis. These forces are shown to be large as compared to the gradient force at $\theta \sim 1/\gamma$, where γ is the relativistic factor, characterizing unperturbed electron motion, $\gamma \gg 1$. The factors differentiating these additional components of ponderomotive forces from the gradient one are given by γ and γ^2.

2.19 G. Ferrante

Evolution of Highly Anisotropic Plasma Distribution Functions in Strong Laser Fields

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Tunnel ionization experiments have demonstrated that as a result of ionization a plasma may be formed exhibiting a highly anisotropic electron velocity distribution function (EDF), with the parallel to the external field degrees of freedom heated much more efficiently than the perpendicular ones. For the plasma physics in general, it is a significant achievement because it provides a new, important object of investigation. In fact, in the past, the creation of highly anisotropic plasmas was limited only to beam injection, and theoretically anisotropic plasmas were looked at as rather exotic study cases.

In this Report, we present a number of results concerning the time evolution of initially highly anisotropic plasmas interacting with a strong laser field. We consider a classical, two-component, fully ionized plasma and solve numerically the appropriate kinetic equation for the EDF.

The analysis is meant to be of rather general interest in the plasma physics context, and, accordingly, different situations are considered. In particular, we consider:

EDF evolution with and without the external field; different EDF initial shapes; very-short-pulsed and constant amplitude fields; the relative importance of electron-ion and electron-electron collisions.
As a rule, for each physical situation of interest, we calculate also the properties of the anisotropic plasma heating and the one dimensional EDF.

2.20 I. B. Földes

Properties of High Harmonics Generated by Ultrashort UV Laser Pulses on Solid Surfaces

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Second and third harmonics of a 15 mJ, 700 fs, 248 nm KrF laser have been generated in laser plasma interactions on solid targets with a maximum focussed intensity of $5 \cdot 10^{15}$ W/cm^2. Mass-spectroscopic and light scattering diagnostics showed, that the prepulse level originating from the amplified spontaneous emission (ASE) of the amplifier must be kept well below 10^7 W/cm^2, otherwise the formation of a preplasma or photoevaporation of the target material will perturb the smooth surface. In case of this low prepulse level the ultrashort pulse interacts with a steep density profile on the solid surface.
The generated harmonics preferred to propagate into the specular direction, and they appear both for p- and s-polarized laser radiation. Polarization of the generated harmonics was determined with a home-made VUV polarizer. It was found that the generated harmonics keep the original laser polarization with an ≈10:1 contrast. An analytical, nonperturbative, local model was developed, which explains the possibility of generating harmonics by the ponderomotive force even for s-polarized laser radiation.
This work was supported by the Hungarian OTKA Foundation under Contracts T023526, T016887 and T029376.

2.21 M. Gavrila

Atomic Spectroscopy in Intense Laser Fields

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The possible energy states of an atom in a laser field of given intensity and frequency are determined by Floquet Theory. As opposed to the field-free case, when the states are static, with the field on they become quasistationary, representing intrinsic modes of ionization of the atom. All possible Floquet states (for all I and w) form an adequate expansion set for the analysis wave packet evolution, and hence the manifestation of physical observables (as formulated in the Multistate Floquet Theory). At high intensities "light-induced Floquet states" (LIS) play an essential role in the analysis, as has been demonstrated recently [1]. We illustrate here these statements on a 1D model, by showing how the spectroscopy of the atom is reflected in the energies of the electrons obtained by pulsed laser ionization. We first determine the Floquet states at all intensities in the range of interest at the chosen w, and then calculate the photoelectron spectra at the end of a realistic pulse. We show that the spectra reveal the Floquet states passed by the atom during its evolution (i.e., its "diabatic paths"). We analyze how the laser pulse characteristics can affect the branching probabilities of the diabatic paths. Our analysis reveals that some of the interpretations adequate at low intensity become invalid when the intensity is high (e.g., the presence in photoelectron spectra of only resonantly enhanced peaks).
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2.22 S. P. Goreslavsky

Photoionization assisted by rescattering: quantum theory in the semiclassical limit

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An approximate but essentially quantum mechanical theory of the photoelectron distributions on the high-energy ATI plateau is discussed [1].The nonstationary Schrödinger equation for an atomic electron in a strong laser field is solved by iterations in the atomic potential [1-3]. The zero order solution describes a direct transition to the continuum in the Keldysh approximation. The amplitude of ionization to the plateau region arises from the first order contribution accounting for the scattering of the ionized wave packet by the parent ion in the Born approximation.
A double integral representing the rescattering amplitude is calculated by a saddle-point method. Equations for stationary points coincide with the equations adopted in

the classical rescattering model [4]. The derived energy-angular distribution exhibits an interference structure and, nevertheless, is formulated in terms used in the classical approach (i.e. "the time of ionization", "the return time" and so on).
It is shown that the standard saddle-point method as well as the classical model itself are not applicable for calculations of the rescattering to quantum states near the classical cutoffs in the energy and emission angle. A modified version of the saddle-point method is used to derive the distribution in this region. A shape of the distribution evolves gradually near the cutoffs and inside the classical boundary on the average matches the result found by the standard procedure.
In both cases the distribution is presented in an analytic form and explicity shows the dependencies on the laser and atom parameters. It is consistent with experimental observations including positions of the cutoff, a decline of the plateau, its overall decrease at higher laser intensities and the influence of the ion core on the electron yield to the plateau. As well the distribution fairly well agrees with the results of direct quantum calculations [2,3] with respect to positions of specific features in the interference structure in the energy and angular distributions. Explicitly known scales of the interference structure provide a useful tool for an open eye search of conditions allowing for to observe experimentally the interference effects on the high energy plateau.

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2.23 R. Grobe

Generation of higher harmonics in relativistic ionization of magnetically dressed atoms

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We review the spectrum of the scattered light that is generated in the interaction of an atom with a very intense laser field and focus on how relativistic effects such as retardation and Doppler shifts can modify the spectra. We will then extend the discussion to a novel regime for which the atom-laser interaction takes place in a static homogeneous magnetic field. In the weak field limit the magnetic field leads to additional sequences of peaks in the scattered light spectrum that accompany the laser's even and odd-order harmonics. We investigate the possibility to tune the strength of the magnetic field to the relativistic resonances [1] to enhance the generation of higher harmonics.

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2.24 S. L. Haan, poster

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Near threshold one-photon photoionization in a one-dimensional delta-function system

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Ionization of a one-dimensional delta function system is analyzed analytically for a range of laser frequencies and intensities in which the channel for one-photon ionization can be partially closed. Expressions for the time development of the populations and for the photoelectron energy spectra are derived and examined. Comparisons with other systems featuring a single discrete state and a continuum are made. Finally, effects of exponentially ramping the laser turn-on are examined.

2.25 M. Ivanov

Optical Twister for Molecules

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Strong infrared laser fields can be used to create an "optical twister"- a field that would exert very large and controlled optical torques on anisotropic molecules, leading to a controlled molecular rotation induced with a simple pulse. Molecular dissociation via rotations is used to demonstrate our method. The scheme distinguishes molecules with different moments of inertia, and thus acts as an optical centrifuge.
Optical twister is created using two strong circularly polarized laser pulses, counter-rotating and positively chirped with respect to each other. The total electric field is linearly polarized, but the polarization vector rotates in the x-y plane with angular acceleration given by the chirp rate. Most diatomic molecules follow the accelerating rotation of the polarization vector. With current femtosecond technology one can achieve extremely fast rotations, breaking bonds in molecules like chlorine.

2.26 A. Jaron, poster

Asymmetries in the angular distributions of above threshold ionization in an elliptically polarized laser field

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We consider above threshold ionization in an elliptically polarized laser field and show by means of our modified KFR model (J. Z. Kamiński et al. Phys. Rev. A **53**, 1756 (1996)) that the asymmetries of the angular distributions of the ionization rates of ATI have their origin in the forces acted by the residual ions on the ionized electrons and the wings and shoulders observed recently in the near threshold region for elliptically polarized laser light (G. G. Paulus et al. Phys. Rev. Lett. **80**, 484 (1998)) are significantly enhanced if the binding potential is accounted for. This means that the inclusion of these forces are essential for a deaper understanding of the finer details of the ATI process. Our investigations show that the Coulomb force not only causes asymmetric angular distributions of the ionization rates, as discussed earlier, but also describes better the wings and shoulders of these distributions if compared with the results of the KFR theory.

2.27 J. Z. Kaminsky, poster

Transitional effects in electron-atom scattering in a laser field near the interface between radiation filled space and vacuum

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We investigate the modifications of the energy spectrum in electron-atom scattering in a laser field if the atom is placed near the interface between radiation filled space and vacuum. Considerable modifications are found if compared with the results for a laser beam of infinite extent. With the advent of femto- and attosecond laser pulses, the investigation of such edge effects will become of relevance in comparing experimental data with theoretical predictions.

2.28 R. V. Karapetyan

Motion of an atomic electron in a strong laser field

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The classical equation of motion of an electron in the atomic field and the laser field is considered in the high-frequency approximation. An effective potential describing an averaged (smooth) motion in these fields is found. The potential differs from Kramers-Henneberger one by an additional term, which is positive and quadratic in the atomic potential. In the limit of strong radiation field - a large amplitude of electron oscillation in this field - it is shown that this term may substantially distort Kramers-Henneberger potential in the vicinity of its minima. Necessary conditions of validity of the averaging procedure of the input equation of motion are found. All these results are obtained for an arbitrary one-dimensional symmetric well with a finite depth simulating of atomic potential and are presented in analytical form.
This work is supported by RFBR grant 98-02-16682.

2.29 C. H. Keitel

Relativistic laser-ion interaction: Dynamics and X-ray radiation

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For several years high power lasers are available in various research laboratories worldwide allowing to obtain further understanding in the weakly and fully relativistic regime of laser atom interaction [1]. Already for intensities of 10^{17} W/cm^2 in the optical regime, the magnetic field component of the laser field begins to induce a substantial drift of the electronic wavepacket motion in the laser propagation direction which may strongly increase the ionization rate [2]. For multiple charged ions, the

ionization rate may be significantly reduced in spite of the relativistic laser intensities, facilitating the relativistic laser - bound electron interaction. For those situations we find unusual dynamical features in the vicinity of the ionic core and the generation of coherent X-ray radiation [3].

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2.30 V. P. Krainov

Thomas-Fermi metal clusters in a laser field

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A new model of Thomas-Fermi metal clusters and cluster ions is developed which describes the electron distribution in alkali clusters with large number of atoms. The well-known jellium model [1,2] is applied for positive ion distribution. The classical multiple ionization of clusters by a strong laser field is considered. The critical barrier-suppression field strength is derived [3]. The ionization degree of clusters has been calculated depending on the laser field strength. The work function is taken also into account. The static polarizability of neutral metal clusters is calculated within the frames of Thomas-Fermi approximation generalized to take into consideration the external laser field. It is shown that the value of the polarizability exceeds the bulk limit because of diffuse form of the electron distribution. The simple analytic expression for the tunneling ionization rate of metal clusters and cluster ions by a low-frequency laser field is found using ADK approach[4]. In particular, the tunneling ionization rate of a neutral cluster is (F is the field strength, A is the work function, R is the cluster radius, and atomic system of units is used)

$$w = \frac{R^3F^3}{8\sqrt{3}\pi^2\,(2A)^{3/2}}\left(\frac{16eA^2}{F}\right)^{2/\sqrt{2A}}\exp\left(-\frac{2\,(2A)^{3/2}}{3F}\right)$$

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2.31 V. P. Krainov

Energy and angular distribution of relativistic electrons in the tunneling ionization of atoms by circularly polarized laser radiation

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Simple analytic expressions are obtained for relativistic electron energy and angular distributions produced in tunneling ionization of atoms by intense laser radiation. Circularly polarized radiation is considered, using the Landau-Dykhne approach. Major differences have been found as compared with the previously investigated case of linearly polarized laser radiation [1]: a circularly polarized intense field produces mainly *relativistic* electrons, while a linearly polarized intense field produces mainly *non-relativistic* electrons. In the limit of a weak field we obtain well known expressions for the non-relativistic energy spectrum and angular distribution of ejected electrons in the tunneling ionization of atoms [2]. (Limited, of course, to the case where the so-called Keldysh parameter corresponds to the tunneling regime of ionization). Simple expressions have been found for: (1) the angle between the direction at which most of the relativistic electrons are ejected and the plane of polarization of the laser radiation; (2) the energy spectrum at this angle; (3) the width of the energy spectrum and the position of its maximum; (4) the angular distribution near this angle and the width of this distribution. Our simple purely analytical results fir energy and angular distributions are in agreement with the numerical derivation of Ref. [3] based on the strong field approximation of Reiss.
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2.32 F. Krausz

Extreme Nonlinear Optics with Few-Cycle Laser Pulses

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Recent progress in ultrafast laser technology has resulted in the generation of 5-fs near-infrared pulses at subterawatt peak power levels [1,2]. In these pulses the electric and magnetic fields perform less than two oscillations within the full width at half maximum of the intensity envelope and the peak amplitude of the electric field can exceed 10^{10} V/cm.

As a consequence, optical fields significantly stronger than the static Coulomb field experienced by bound electrons in atoms and molecules can be "switched on and off" within rise and fall times comparable to the oscillation period of the field. This capability now permits researchers to expose matter to extremely strong optical fields before being fully ionized and confines the effective interaction time to a single light period [3].

The implementation of light-matter interactions under these extreme conditions significantly pushes the frontiers of nonlinear optics and high-field physics. Important implications include the laboratory production of coherent sof x-rays via high-order harmonic generation in gases down to wavelengths approaching 2 nm [4-6], the extension of reversible nonlinear optics in solids to intensities in excess of 10^{14} W/cm^2 [7], and the promise of generating *single* xuv pulses with subfemtosecond duration [3].

The talk will review these advances and their expected impact on other areas of research and technology.

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2.33 M. Yu. Kuchiev

Quantum theory of a high harmonic generation as a three-step process

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We demonstrate that the process of high harmonic generation (HHG) by atoms in a strong laser field can be looked at as a three-step process. The first stage of it is the multiphoton ionization of an atomic electron into some ATI level. During the second stage the ionized electron propagates in a laser-dressed continuum. Subsequently, stimulated (laser assisted) recombination brings the electron back into the initial state with emission of a high-energy photon. This physical picture was suggested in [1] for a number of phenomena and called *atomic antenna*. The major role in the approach considered plays the *factorization technique* [2] which ensures that for large number of the absorbed laser quanta, $n \gg 1$, the amplitude of a complicated process, HHG in our case, can be presented as a product of more simple amplitudes, which describe the ionization, propagation and recombination. These three amplitudes are described by clear, mostly analytical expressions. This fact allows a detailed physical interpretation for all features which exhibits the probability of the HHG with variation of the frequency and intensity of a laser field and the number of laser quanta absorbed.
In order to verify a validity and accuracy of the theory developed, it has been applied to the case of the harmonic generation by H^- ions. We find a very good quantitative agreement with the previous calculations of [3] both for weak and strong fields for a wide range of the laser quanta absorbed. Contributions of different ATI channels add up coherently. The coherence effects are responsible for a number of features exhibited by the probability of HHG. In particular, they are responsible for an exponential decrees of the probability of HHG for large number of the absorbed laser quanta.
The reliability of the developed approach supplements its conceptual significance with practical efficiency. The virtue of this scheme is further supported by a good accord between the calculations in length and velocity gauges for the high-energy photon.

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2.34 H.-J. Kull

Multiphoton processes in electron-ion scattering in strong laser fields

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Electron-ion scattering in strong laser fields is accompanied by high-order multiphoton processes, responsible for the plateau region in single-atom ATI-photoelectron spectra [1] and for the absorption of intense laser light in collisional plasmas [2].
In the present work, the scattering problem is treated by solving the time-dependent Schrödinger equation (TDSE) numerically by a finite-difference alternating direction

implicit method (ADI). The numerical method accounts for the specific boundary conditions of scattering solutions, requiring an incoming plane wave at the grid boundaries. The method is applied to the interaction of the electron wavefunction with regularized one-dimensional and three-dimensional Coulomb potentials in the presence of a time-dependent electric field. Results are discussed for the screening of the ion by a homogenous electron density, for the spacetime-evolution of the scattering waves and for electron energy spectra. A plateau region in the high-energy spectrum is obtained. Comparison is made with classical models and previous results from the Kroll-Watson perturbation theory of potential scattering in an intense electromagnetic wave [3].

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2.35 N. J. Kylstra

Laser pulse effects in the stabilization of atoms in intese, high frequency laser fields

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Atoms in intense, high-frequency laser fields exhibit the remarkable property that they can stabilize against ionization with increasing laser intensities [1]. We have considered in detail, using one- and two-dimensional models, the influence of the laser pulse shape and duration on the stabilization dynamics.

We first discuss the specific case of a rectangle pulse. A high frequency approximation is formulated and results for a one-dimensional model are compared with the numerical solution of the time-dependent Schrödinger equation. In this high frequency regime, ionization occurs predominately via "shake-off" to the low energy continuum states. The effects of finite pulse turn-on and turn-off times are discussed, and a general high frequency approximation for arbitrary, short laser pulses is investigated. We find that for the cases studied, the high frequency approximation accounts for the main features seen in the laser-atom interaction dynamics. Next, by considering trapezoidal and sine-squared pulses, the influence the form and duration of the laser pulse have in determining the extent of stabilization is considered for a wide range of laser intensities. In particular, the ionization mechanisms are analyzed and shake-off and photoionization regimes are identified. We have also varied the pulse duration to investigate how the classical momentum and position displacement induced by the laser pulse influence stabilization. The effect of the range of the potential on stabilization is also considered. The structure of stabilized wavepackets for a two-dimensional model hydrogen atom interacting an intense, high frequency laser pulse as a function of the laser pulse ellipticity and laser pulse rise-time is discussed next. In particular, for a fixed pulse shape

we investigate the structure of the stabilized wavepacket for different ellipticities and compare the generated wavepackets with the corresponding Kramers Henneberger (K-H) ground states. Laser pulse turn-on effects are studied by comparing the structure of the localized wavepackets and ionization for three different ellipticities and for various pulse turn-on times. We find that adiabaticity is most easy achieved with linear polarization, the wavepacket is more stable for circular.

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2.36 C. Lyngå

Coherence properties and applications of high-order harmonics

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When intense, short pulse laser-light is focused into a gas jet, high-order harmonics of the fundamental laser field are emitted. This harmonic radiation presents similar attractive characteristics as the fundamental field, i.e. it is coherent, collimated, of short pulse duration and has a high brightness. The harmonic radiation is thus of interest not only as a way to study the interaction between an atom and an intense laser field from a fundamental point of view, but is also a promising source of short wavelength radiation. Although harmonic radiation has been studied extensively over the last decade and is now quite well characterised, the temporal coherence has been explored only recently [1,2].

We have studied the temporal coherence of high-order harmonics by observing the far field interference pattern of harmonics created in two separate sources, but originating from the same laser (Ti:S, 110 fs). By changing the delay between the two pulses generating harmonics we can measure the coherence time of the harmonic radiation by observing the far-field pattern and recording the decrease of contrast. We find that the far-field pattern consists of two distinct spatial regions with different coherence times. There is an intense inner part with a long coherence time and an outer part with a

considerably shorter coherence time. These results will be discussed and compared to the predictions of the semi-classical model. In particular, the influence of the intensity-dependent dipole phase will be discussed [3].
The excellent coherence properties of harmonic radiation opens up possibilities to do interferometry in the XUV region, a wavelength region where optical components are difficult to use. We have recently demonstrated this possibility by inserting a thin aluminium filter in one of the two harmonic beams and detecting a phase shift in the transmitted beam by observing the fringe shift in the far field fringe pattern. These results will be presented.

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2.37 S. I. Marmo

Polarization Effects in Two-Photon Two-Color Ionization

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The recent improvements in experimental technques allow to study the polarisation dependencies in atomic photoprocesses including the ionisation of atoms. One of most noticeable polarisation effects is the circular dichroism (CD) which consists in the dependence of the processes probabilities upon the sign of the photon circular polarisation ξ. We present here the results of the experimental and theoretical study of the polarisation effects under the two photon two color ionization (TPTCI) process.
If the initial atomic state is spherically symmetric, then the TPTCI probability calculated in the dipole approximation is

$$\frac{1}{II'}\frac{dW}{d\Omega_{\mathbf{p}}} = A_1|(\mathbf{e}'\mathbf{e})|^2 + A_2|(\mathbf{e}'\mathbf{n})|^2|(\mathbf{en})|^2 + A_3 Re\left\{(\mathbf{e}'\mathbf{e})(\mathbf{e}'^*\mathbf{n})(\mathbf{e}^*\mathbf{n})\right\} + A_4 \,\mathrm{Im}\left\{(\mathbf{e}'\mathbf{e})(\mathbf{e}'^*\mathbf{n})(\mathbf{e}^*\mathbf{n})\right\}, \qquad (3)$$

where $I, \mathbf{e}$ and $I', \mathbf{e}'$ stand for the intensity and the polarisation vector of the first and the second waves respectively, $\mathbf{n}$ is the unity vector along the photoelectron linear momentum direction, A_{1-4} are some invariant atomic parameters which can be expressed in terms of the ionisation matrix elements and the scattering phases. If one of the photons is linearly polarised $\mathbf{e}^* = \mathbf{e}$, and the other is polarised elliptically, then the polarisation factor in the last term in (3) can be rewritten using $2Im\left\{(\mathbf{e}'\mathbf{e})(\mathbf{e}'^*\mathbf{n})\right\} = -\xi'(\mathbf{k}', \mathbf{e}, \mathbf{n})$, ($\mathbf{k}'$ being the unity vector along the wave propagation direction), which demonstrates explicitly the existence of CD.
In the experiment, argon atoms are photoionised by one photon from femtosecond Ti:S laser (800nm) and one of its high harmonics elliptically polarised. Both photon beams

are collinear and focused into the target gas by a multilayer UVX spherical mirror. Electrons are detected at a right angle from the common direction of propagation. The resulting photoelectrons are analysed by a time-of-flight spectrometer in a small collection angle for different polarisation states of the two photons. As the calculations show, the CD value depends significantly on the radiation frequency. For instance, the difference of the TPTCI probabilities for the left and right circular polarisation of the ω' photon is about of few percents under $\omega \sim 1.5|E_0|$, $\omega' \sim 0.1|E_0|$ (above-threshold UVX/IR ionization); and this difference cannot be observed experimentally. However, under $\omega < |E_0|$, $\omega' \sim 0.1|E_0|$, the value of CD is about of tens percents. The further experimental measurement is planned for the polarisation effects.
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2.38 Ph. Martin

Time resolved photoemission spectroscopy using high order harmonics

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The relaxation dynamics of excited carriers is a key problem in the field of ionizing radiation-matter interaction. For instance optical breakdown in solids submitted to high laser fields or the formation of defects in the traces of swift heavy ions can be understood only with a good knowledge of the balance between the different energy relaxation mechanisms and their respective rates. The most powerful tool to measure the energy distribution and its temporal evolution is time resolved pump probe photoemission spectroscopy, using short laser pulses. The energy range is however limited to a few eV, and the experiments have been mainly devoted to metals and semiconductors, where photoexcitation of a high density of carriers is easy. We have performed for the first time the same type of experiment by using a high order harmonic of a Ti-Sa laser (800 nm, 60 fs) as a pump and the fundamental as a probe. This improvement of the pump probe photoemission technique has the considerable advantage of extending the energy of photoexcited carriers in the range of 20-50 eV, which is extremely important in the case of wide band gap materials. Moreover the photoelectron energy arising from the pump and the probe pulses lie in completely different ranges, making their identification much easier. As an example, we will present the result obtained in quartz (a-SiO2). We have measured the relaxation of electrons excited by the 25th harmonic (39 eV, 50 fs) of the laser. The latter is generated in an Argon jet and focused by a spherical Bo-Si multilayer mirror which selectively reflects the desired harmonic. The population of electrons excited with the harmonics and extracted by the fundamental decreases with a rate of approximately 5 ps for 30 eV electrons. This apparent lifetime

is much longer than the electron trapping time measured in pump probe experiments (150 fs) in which the energy of photoexcited carriers lies in a few eV range [1,2,3]. The experimental procedure will be described in details and the consequence of this important result on our knowledge of electron-phonon coupling and impact ionization will be discussed.

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2.39 A. Maquet

Relativistic effects in atom-laser interactions

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The advent of ultra-high intensity (table-top) laser sources, makes possible the observation of two distinct classes of relativistic effects in atom-laser interactions. One class involves the standard influence of relativity on the electronic structure of high-Z atoms. Another class of effects originates from the fact that an atomic electron in the presence of an ultra-strong laser field can experience a significant mass shift and acquire relativistic velocities as its ponderomotive (quiver) energy can become comparable to its rest mass.

Relativistic structure effects in high-Z systems are expected to play a significant role on the magnitude of transition amplitudes for multiphoton processes. For the first time, the availability of a new generation of laser-generated sources of coherent radiation in the X-ray range, (either from harmonic conversion or from X-ray laser devices), opens the possibility of observing multiphoton transitions involving inner-shell states of heavy atoms or ions. We shall report the results of analytical and numerical calculations for two-photon bound-bound transitions in hydrogenic high-Z ions, [1].

On the other hand, when an isolated atom is exposed to an ultra intense pulse of an infrared laser, it is expected that the atom will be at once ionized. Under such extreme circumstances, the response of a macroscopic sample of atoms will be dominated by the relativistic dynamics of the laser-created plasma. It is then of interest to address the question of the changes induced by relativity in the cross sections for the free-free transitions, i.e. inverse bremsstrahlung and/or stimulated bremsstrahlung, occurring in the course of the scattering of fast electrons in the Coulomb field of nuclei, [2].

We shall address also the question of the signature of genuine atom-laser effects, to be distinguished from standard strong-field ponderomotive or laser-plasma interactions. It appears in fact that, under some well defined conditions involving a two-color scheme, it is in principle possible to find the signature of such effects in Above Threshold Ionization (ATI) spectra, [3].

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2.40 S. Meyer

High-order harmonic generation in absorbing media and high-order parametric amplifiers

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We report on our progress in investigations of high-order harmonic generation and frequency mixing processes in gaseous and plasma media. These investigations are important for the improvement of the high-order harmonic efficiency (above 10^{-5}), which is still a challenging problem. Theoretical models and experimental results are presented. Phase-matching, defocusing and absorption effects are discussed, which show that the maximum harmonic efficiency is limited by the absorption of the harmonic signal.

In order to overcome this limitation the development of high-order parametric amplifiers (HOPAs), as an alternative to the existing coherent XUV radiation sources, is suggested. A theoretical description and gain calculations are presented. Experimental results demonstrating the possibility to extend the optical parametric amplification (OPA) techniques into the VUV and XUV range are reported.

2.41 B. Milošević

Control of High-Harmonic Generation and Laser-Assisted X-Ray–Atom Scattering with Static Electric and Magnetic Fields

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We consider the use of strong static fields to control two related atomic processes: laser-assisted x-ray–atom scattering (XAS) and high-harmonic generation (HHG). We first analyze the laser field intensity dependence of the differential cross section (DCS) plateau structures for the laser-assisted XAS process in the presence of a static electric field as a function of the number of photons exchanged with the laser field. Besides the recently discovered [1] extended plateau for absorbed photons, which indicates a substantial increase of the scattered x-ray energies, a new plateau, having many orders of magnitude larger DCS, appears for higher laser field intensities. We show furthermore a connection between this process and HHG. We also consider control of HHG with static electric and magnetic fields which are parallel to the laser polarization. The B field can considerably increase the harmonic intensity [2]. The rate of a chosen harmonic is maximal whenever an integer multiple of the cyclotron period of the electron's motion perpendicular to the magnetic field is equal to the return time to the nucleus of the laser-field-generated electron wave packet in the intermediate state. While the B field has only a modest effect on the plateau cutoff positions, the static electric field can introduce additional plateaus and cutoffs. A properly chosen combination of static E and B fields can increase both the emission rate and the maximum harmonic order. The locations and magnitudes of the plateaus, both for XAS and HHG, are explained using the classical three-step model.

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2.42 P. Mulser

Present understanding of superintense laser–solid interaction and prospects for applications

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The interaction of laser beams with dense (solid) targets is studied theoretically in the intensity range 10^{15} to 10^{21} W/cm^2. In this domain initiation of plasma formation occurs due to nonlinear multiphoton, i.e.field ionization. An overview on the ionization dynamics in superstrong fields is presented and a physical interpretation of the phenomena is given. Ionization rates are presented and compared with corresponding results from leading analytical theories; in addition, spectra of escape energies are shown and their consequences for the early plasma temperature are analyzed. Collisional heating is effective in the very early stage of interaction only. With increasing electron temperature ac runaway effect sets in and the plasma becomes collisionless. To study collective absorption in this stage 3D3P Vlasov as well as 3D PIC simulations are performed. In flat targets up to 40% absorption is found with a maximum at 70 of incidence. When the target is deformed by ablation pressure collective absorption is enhanced up to 80% for a normally impinging beam. The generation of hot electrons in the MeV energy region is the salient signature of superintense laser-plasma interaction. Their fraction is determined by the beam intensity, the frequency and the plasma gradient around the critical surface. At 10^{18} W/cm^2 μ^2 they are strongly collimated by the selfgenerated magnetic field and form a channel of considerable length, an effect seen also in experiments. At 10 - 100 times increased irradiance the collimated channel decays into numerous fibers, each of them surrounded by a cold return current. Such strucures proof to be highly dissipative, hence representing anomalous energy deposition in any nearly arbitrarily overdense plasma. The field of potential applications is outlined briefly.Two kinds of applications will be discussed: (1) ultrafast optical shutters and microcavity engineering, both based on rapid field ionization, and (2) the fast ignitor concept. In the latter case underdense beam transport is calculated and various ignition scenarios are presented. The implications of the anomalous filamentary hot electron transport on the feasibilty of fast ignitor schemes are discussed.

2.43 H. G. Muller, plenary

Resonance enhancement of recollision processes in strong-field photoionization as revealed by accurate numerical simulation

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Solving the time-dependent Schrödinger equation has grown into a very powerful tool for studying photoionization processes in strong laser fields, both in the multiphoton and tunneling regime. Both calculations and experiments have shown that resonances can have dominant effects on the quantum dynamics of the ionization process, and for linear polarization quantitative agreement can be obtained between precision measurements of the electron spectrum and numerical simulations. The latter, however, have the advantage that they are open to much more detailed analysis. Arbitrary polarizations require 3D grids, and only a small part of the much larger parameter space has been touched by simulations. In the tunneling regime calculations are difficult because of the large electron energies involved. Correlation effects in the 3D real world do require 4D or 5D grids, and at the moment closely border the impossible. In this talk the most recent and most interesting examples of the various kind of simulations will be presented, in 2, 3 and (hopefully) even 5 dimensions, with the emphasis on resonance and interference phenomena.

2.44 N. B. Narozhny

QED Effects in a Strong Two-mode Plane Electromagnetic Wave

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The processes of photon emission by an electron and pair production by a photon colliding with a two-mode plane linearly polarized electromagnetic wave are considered. In contrast to the case of circularly polarized wave the total probabilities include terms arising from interference of matrix elements corresponding to different numbers of photons but equal total four-momentum absorbed from the two modes of the external field with commensurable frequencies. Due to the presence of the interference terms the total probabilities exhibit dependence on the phase shift between the two modes. It is shown that contribution of the interference effects is optimal if the ratio of the frequencies of the modes is equal to three.

We compare the probabilities of the considered processes in a monochromatic wave and in the two-mode wave which arises after splitting of the original monochromatic wave into two components and transmitting one of them through a triple crystal. It is shown that under certain circumstances the probability of pair creation in the two-mode field can become higher than in the original wave.

2.45 N. B. Narozhny

Relativistic Ponderomotive Effect

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A model of axially symmetric stationary focused laser field which is an exact solution of Maxwell equations is presented. This model can be modified to describe a laser pulse of finite duration if spatiotemporal inhomogeneity of the field is small. The modified model is an approximate solution of Maxwell equations.
Scattering of a relativistic electron in the suggested laser field is considered. Since for the incorporated model of the laser field two scales of inhomogeneity exist, the movement of the electron can be split into fast oscillatory and slowly changing translational movements. The equations describing translational movement averaged over fast oscillations are obtained and expression for an analogue of nonrelativistic pondeoromotive force is derived. Solutions of the averaged equations of movement are found and scattering cross sections for electrons colliding with the focused laser pulse are calculated. The effect of electron reflection from the laser pulse as well as the surfing effect which were first observed and described by Bucksbaum *et al.* [1] are present in our model.

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2.46 E. A. Nerserov, poster

The amplification of high harmonics in the process of ATI

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The effect of high harmonic [HH] amplification in the process of its passing through the pumping laser +atom interaction volume is con sidered.To estimate the gain the two probabilities were calculated. The first one corresponds to the exitation of atom into the continuum by the pumping wave and then the recombination down to the ground state of atom with HH emission stimulated by probe wave. The second one corresponds to the exitation of atom into continuum by HH probe wave and then the stimulated by pumping laser wave transition down to the atomic ground state.These two probabilities are different if the recoil energy of atom in the process of quanta emission and absorbtion is taken into account. This energy is small but the phase matching effect compensates this smallness.As a result the gain of probe wave with the frequency of HH is enough to be measured.The proposal of experiment to measure the gain with the help of two atomic jets is discussed.

2.47 S. Nuzzo

Elementary Kinetic Theory of Strong-Field Frequency and Multiplication Wave-Mixing

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Since many years, the laser-plasma interaction (LPI) phenomena are a subject of permanent interest and investigation. Besides the usual motivations, related to perspective, very important applications, the continuing attention to the LPI issues is stimulated by the present-day experimental situation, characterized not only by the growing availability of laser systems with unique properties (concerning pulse duration, intensity and so on) in many research laboratories and powerful computation means, but also by the possibility of producing plasmas with unique properties. As an instance of such a new kind of plasmas, we quote the plasmas produced via tunnelling ionization, which are found to be highly anisotropic. Solution of appropriate kinetic equations, Montecarlo and Particle-in-Cell simulations are among the methods used to study such cases. A simplified description of plasma behavior under the action of a radiation field, in the context of weak field LPI, is accomplished by the so called "Elementary Kinetic Theory" (EKT), dealing with the description of a representative, "average" plasma electron.
In this paper we apply the average electron model to describe frequency and multiplication mixing in a colllisional plasma. The model is based on the equations of the first two moments of the electron velocity distribution.
The coupled equations are solved numerically to obtain the spectrum of the electron velocity in the presence of the two fields for an arbitrary temperature dependence of the collision frequency in weakly and strongly ionized plasmas. The nonlinear part of the electron velocity is then included in the Maxwell equation to study the wave-mixed signal. Numerical calculations are reported for the case of polarization signal resulting from four-wave mixing. We expect to report also on results on the same issues obtained using more sophisticated calculation tools, such as Monte Carlo method and solution of the Boltzmann equation.

2.48 D. Persano Adorno

Far-Infrared Harmonic Generation in Semiconductors. A Monte Carlo Simulation

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Harmonic generation in semiconductors is of interest in its own right, but it may prove useful also for the general understanding of the several features of this highly nonlinear process. In fact, numerous physical mechanisms may potentially act to produce harmonics generation, and the elucidation of their separate influence may well yield interesting information to the topic. In the far-infrared region, linear as well nonlinear optical properties of doped semiconductors are mainly determined by the motion of free carriers caused by the electric field of the incident wave. The measurements of nonlinear optical properties in the far infrared gives then the possibility of investigation of nonlinearity in the transport of carriers in semiconductors. Moreover the far-infrared frequencies are well below the absorption bands due to phonons. In this paper we study the harmonic generation from an GaAs sample using a Monte Carlo simulation for the motion of the free carries in the external electromagnetic field combined with the nonlinear electrodynamic equations. The strategy of the simulation is the following: i) we perform Monte Carlo simulation of the time dependent drift velocity for different values of the electric field amplitude and frequency; ii) from the Fourier coefficients of the drift velocity we calculate the dependence of the nonlinear dielectric susceptibility χ_n as function of the electric field amplitude; ii) solving the nonlinear wave equation at the n-th harmonic frequency we get the amplitude and intensity of the n-th harmonics. In our simulation the conduction band of the GaAs is represented by three nonparabolic $(\Gamma - L - X)$ valley. The electron collision mechanism included are: collision with impurity, collisions with optical phonons polar and non polar, collisions with acoustic phonons.
Among the results of our simulation to be reported at the conference, we anticipate that the harmonic spectrum contains only odd harmonics and that even harmonics too appears is a constant electric field is present. At the conference we will report: 1) on the efficiency of the harmonics generation as a function of the intensity of the fundamental field; 2) on the efficiency as a function of the free carriers temperature and concentration.
Finally, we hope to report on similar calculation for Si as well.

2.49 R. Parzyänski

The effect of nonresonant l=1, n=0 electric-dipole migrat ion on Rydberg-atom photoionization

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We study the effect of direct l = 1 electric-dipole couplings between Rydberg states of opposite parity but the same principal quantum number nl on the photoionization from a high-n Rydberg state by a pulse of optical frequency and duration much longer than the optical period. These nonresonant couplings, of the detuning amounting to the optical frequency, are shown to change dramatically the nominal one-photon ionization of a high-n Rydberg state if the laser intensities (moderate) ensure the Rydberg-to- Rydberg Rabi frequencies to approach and exceed the optical frequency. One spectacular effect is the ejection of photoelectrons at the right angle with respect to the direction of linear polarization of light, in the case when the atom was initially in a spherically symmetric s state. The other effect is the ionization suppression, i.e., a profound decrease in the ionization yield as compared to the yield based on the Fermi Golden Rule. The calculated time-averaged populations of different-l states of the same n point to the l = 1 migration of the population towards higher-angular-momentum states as the reason for these new photoionization behaviours. Our results for photoionization are in agreement with the results for photoexcitation of Corless and Stround (Phys.Rev.Lett. 79, 637 (1997)) who originally raised the question of nonresonant 1, n = 0 mixing of Rydberg states by an optical field of a moderate strength.This kind of mixing differs from the l = 2, n = 0 Raman mixing and needs an approach not suffering from the rotating wave approximation.

2.50 V. T. Platonenko

Attosecond pulse generated with an ultrashort laser pulse

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We consider generation of a high frequency radiation with a short laser pulse taking into account diffraction of the pump beam and diffraction of the generated field. Using method derived in [1,2] we calculate the whole generated field in the far zone and show that fields with different frequencies are focused at different distances from the target. Hence at a fixed point at beam axis relatively narrow part of generated spectrum (namely the part focused at the point) contributes to the high-frequency field. Thus field in the far zone after suppression of the low-frequency part (corresponding to several lower-order harmonics) forms a series of focused attosecond soft x-ray pulses. In our calculations pulses with duration about 100 attoseconds and intensity more than 1 GW/cm^2 were obtained.
Technically attosecond pulses can be filtered from the whole generated field (that includes low-frequency part) with a system of pinholes. Generated in a very short laser pulse (containing several half-cycles) attosecond pulses of the series have different frequencies and intensities. Their features can be treated from the point of view of semiclassical theory: the amplitude of a pulse is determined mainly by ionization

probability (i.e. by the laser field amplitude at the moment of ionization), and its frequency is determined mainly by the field amplitude at the moment of pulse emission (i.e. the moment of recombination). Using laser pulses shorter than three half-cycles one can obtain a single attosecond pulse suppressing others by pinholes. The efficiency of this suppressing depends on the pump field phase relatively to the pulse envelope: the suppressing is more efficient for a "sine-like" laser pulse and less efficient for a "cosine-like" one.

Calculations carried out with thick targets show that dispersion limits the intensity of attosecond pulses about in the same way as it limits the intensity of a single harmonic with central frequency of the pulse and does not affect the pulse duration essentially.

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2.51 V. T. Platonenko, poster

Analytical formulae for high harmonic amplitudes

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In the framework of quantum theory of high-harmonic generation by a single-electron atom the following formula to estimate an amplitude of 2n+1-th harmonic of a time derivative of the electron momentum is obtained:

$$f_{2n+1} \approx -\frac{eE}{3}\sqrt{\frac{I_p}{\hbar\omega}}\left(\frac{2}{\mu}\right)^{n+1/2} n! \times \left[J_{n+1}(aU)J_{n+1+1/2}(\mu)\left(\frac{2}{\mu}\right)(n+1) + iJ_n(aU)J_{n+1/2}(\mu)\right]\exp\{i\phi\} \tag{1}$$

$\mu = \sqrt{\frac{a}{b}}\left[\frac{I_p}{\hbar\omega} + \frac{aU}{\hbar\omega} - \left(n+\frac{1}{2}\right)\right]$, $\phi = 8b + \frac{2n+3}{4}\pi + \left[\frac{I_p}{\hbar\omega} - \left(n+\frac{1}{2}\right)\right]x_0$,

here E and ω are laser field amplitude and frequency, I_p and U are ionization and ponderomotive energy, constants are $a \approx 3.17/2$, $b \approx 0.406$, $x_0 \approx 4.06$, $J_n(x)$ is a Bessel function of n-th order. The formula is valid only for several plateau harmonics near cut-off, and for more high-frequency ones. Note that all plateau harmonics have approximately the same intensity, so one can use the formula (1) with n corresponding to the high-frequency part of plateau to estimate the plateau intensity. Under $U \geq I_p$ the formula can be essentially simplified:

$$f_{2n+1} \approx -\frac{eE}{3}\sqrt{\frac{I_p}{\hbar\omega}}\, iJ_n(aU)\frac{1}{\sqrt{n+1}}\exp\{i\phi\} \tag{2}$$

Intensity of the highest plateau harmonic as a function of ponderomotive energy, calculated numerically (dot line), using formula (1) (thick line), and formula (2) (thin line).

In the mentioned above region of harmonic numbers formulae (1) and (2) agree with numerical calculations carried out in the framework of theory [1] (see figure).

The power of single atom emission on harmonic frequency is $\frac{2}{3}\frac{e^2|f_{2n+1}|^2}{c^3m^2}$. An analysis of equation (1) shows, that the power occurs approximately equal to production $w_i w_r 3U/N$, where w_i is a ionization rate, w_r is a probability of recombination of an electron going back to the parent ion, $3U$ is the maximum kinetic energy of recombining electron, N is the whole number of plateau harmonics.

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2.52 A. M. Popov

Hydrogen atom in a strong laser field

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The behaviour of the 3D hydrogen atom in a strong linearly polarized laser field of femtosecond duration is examined by method of the direct numerical integration of the non-stationary Schrödinger equation [1,2]. The investigation was performed in a wide range of laser pulse parameters and for different initial atomic states $| \, nlm\langle$. Different mechanisms of the ionization suppression (interference and Kramers - Henneberger stabilization) are found to take place and to change each other in dependence on laser intensity. The conditions causing the stabilization of one or another type are investigated. The results of the simulation of the ionization dynamics of the hydrogen atom in a circular Rydberg 5g,m=4 state are compared with the data of recent laboratory experiments [3] on ionization of hydrogen-like excited state of Ne(2p5,5g,m=4). The possibility to interpret the results of numerical and laboratory and numerical experiments in terms of different mechanisms of the stabilization is analyzed.

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2.53 S. V. Popruzhenko, poster

Scalings of the interference structure in the photoelectron distributions on the ATI plateau

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The energy-angular distributions on the high-energy ATI plateau showing the quantum interference effects has been recently calculated in the tunneling regime [1-4]. Quasi-classical analysis of the rescattering amplitude by the saddle-point method [3,4] allowed to identify interfering components of the ionized wave packet and to present explicit estimates for the characteristic scales in the interference structure. It was found that a total number of interference "periods" in the energy spectrum along the direction of polarization between $2U_p$ and $10U_p$ equals to $N \approx Z_F/3$ (here $Z_F = 4U_p/\hbar\omega$; U_p is the ponderomotive potential; ω is the laser frequency). This estimate means that a separate "period" has a length $(6 \div 7)\hbar\omega$ which does not dependent on the laser intensity.

The distribution derived by a standard saddle-point method diverges when energy ϵ or emission angle θ approaches their classicsal cutoffs $\epsilon_{cl}(\theta)$ and $\theta_{cl}(\epsilon)$. For such ϵ and θ a modified saddle-point method is to be used and leads to the energy-angular distribution proportional to the square of the Airy function. This result allows for to trace how the distribution evolves across the classical boundary and to make various explicit conclusions. For example, now a characteristic scale in the energy spectrum at fixed θ is estimated as $\delta\epsilon/U_p \approx 7.7/{Z_F}^{2/3}$ ($Z_F = 126$ for $I = 10^{15} W/cm^2$ and $\omega = 1.58 eV$). Its nonscaled value $\delta\epsilon \approx 2F^{2/3}$ does not depend on the laser frequency. Another example: the largest side lobe in the angular distribution for energies $\epsilon \geq 8U_p$ is located at $\theta_{max}(\epsilon) = \sqrt{(10 - 7.7/Z_F^{2/3} - \epsilon/U_p)/7.8}$. That formula gives $\theta_{max}(9U_p) = 17.1^0$ and $\theta_{max}(8U_p) = 26.7^0$ for $Z_F = 126$. The corresponding numerical results in ref.[4] are 20^0 and 30^0. Effect of spatial and temporal averaging on the distribution near the classical boundary will be discussed in the conclusion.

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2.54 R. M. Potvliege

Quasienergy spectrum and multiphoton dynamics

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In order to understand the behaviour of an atom exposed to a laser pulse that is neither ultra-intense nor ultra-short, it is often helpful to represent the pulse as a rapidly oscillating electric field with a slowly varying amplitude, and the atom as a superposition of dressed (Floquet) bound states decaying by photoionization. These dressed states correspond to particular quasistationary solutions of the time-dependent Schrödinger equation for the atom in a field of constant intensity and frequency. In this picture, the dressed states adiabatically follow the temporal variation of the intensity during the passage of the pulse, the variation inducing only fairly slow changes in the coefficients of the superposition.
The following cases will be analysed within this approach: the transfer of population between dressed states at Stark-shift induced resonances corresponding to a true crossing in the real part of the quasienergy, adiabatic stabilization in ultra-short high-frequency pulses, and the appearance of light-induced states at high intensity.

2.55 R. M. Potvliege

Adiabatic stabilization of circular states: phase-control in two-colour fields and magnetic couplings

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The rate at which an atom undergoes photoionization in a weak stationary laser field is normally an increasing function of the intensity. However, if the photons energy exceeds the binding energy of the initial state, this rate eventually levels off at a certain intensity and starts to decrease: above this intensity, the atom becomes increasingly stable against ionization, instead of becoming increasingly unstable. This high-frequency effect, often called adiabatic stabilization, has been experimentally observed in neon for the case where the atom is initially in a moderately excited circular state [1]. The interpretation of the data in terms of adiabatic stabilization tails well with the results of Floquet and time-dependent calculations in hydrogen [2].
The Floquet calculations of Ref. [2] have been extended in two directions: (1) the total rate of ionization has been obtained beyond the electric dipole approximation; and (2) adiabatic stabilization in a coherent superposition of a strong laser field and its second or third harmonic has been investigated. The non-dipolar couplings have been found to be negligible in the visible, at intensities comparable to those used in the experiment. The variation of the rate with the relative phase of the two fields is consistent with that recently described for a one-dimensional model atom [3], but is significant only at very high intensities.

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2.56 C. Reinhardt, poster

Efficient VUV and XUV generation with a fs KrF laser

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Investigations on low-order harmonic generation and difference-frequency mixing in gas jets and hollow-core fibers have been performed. As a pump, short pulse (400 fs) KrF laser radiation is used. A short wavelength pump allows to get a higher conversion effieciency into the VUV and XUV spectral range than with Ti:sapphire lasers [1]. Experiments on near-resonant two photon and four photon difference-frequency mixing schemes and investigations on parametric gain and gain transfer processes will be presented. First applications of coherent VUV and XUV radiation will be discussed.

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2.57 A. Scrinzi

Quasistatic Laser Field Ionization of Hydrogen and Helium

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We investigate ionization of Hydrogen and Helium by ultrashort laser pulses at wave lengths between 800 and 250 nm. The validity of the quasi–static description of ionization at field strength where the Coulomb barrier is suppressed is demonstrated by comparison with the solution of the time–dependent Schrödinger equation. To obtain agreement one needs to use correct static field ionization rates, which we obtain for H and He by a numerical complex scaling calculation. The rates for He are, to our knowledge, the first quantitatively accurate results for a fully correlated two–electron atom. Commonly used analytic formulae, while being asymptotically correct in the low–field limit, fail at higher field strength. The agreement of numerical and analytical static field ionization rates at low field supports the single–electron picture of ionization of He, on which the analytic formulae are based. The much lower ionization rates of He at barrier suppression field strengths compared to analytic results show that up to 40% higher harmonics than anticipated may be generated from He.

2.58 E. A. Shapiro, poster

Quantum Control via Localized Rydberg States

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Quantum states of a Rydberg atom dressed in a resonant microwave field can be localized near certain classical trajectories. By controlling the microwave field parameters, one can control the localized quantum state and thus adiabatically transfer a quantum system into a desired final state. We describe this process analytically and find the suitable field parameters for quantum control in Rydberg atoms.
Next, we numerically solve the time-dependent Schrödinger equation *ab initio* to demonstrate how a localized state can be used to transfer population between hydrogenic Rydberg states with various principal quantum numbers and angular momenta. Our calculations show that one can adiabatically transfer population between Rydberg states with about 95% efficiency. Thus quantum control via localized states is a credible adiabatic method for inter-manifold control of Rydberg states and is a good extension of the known set of adiabatic methods of quantum control of Rydberg states.
This work was supported in part by NSF grants PHY-9304335 and PHY-9415583, and CRDF grant RP1-244.

2.59 M. O. Sukharev

High-order harmonic generation by H_2^+ in a strong laser field

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High-order harmonic generation by a hydrogen molecular ion in a strong linearly polarized laser field is theoretically reconsidered. Franck-Condon factors for ionization of a neutral hydrogen molecule are derived taking into account the laser field. Harmonic spectra are derived for the values of the field strength amplitude from $5 \cdot 10^7$ V/cm to $3 \cdot 10^8$ V/cm. Nuclear dynamics of a hydrogen molecular ion in a laser pulse is investigated within the frames of classical mechanics. The problem of alignment of the molecular axis along the field polarization is also considered [1]. The basic mechanism of harmonic generation is the spontaneous radiation of an electron during its transition from the odd excited state to the even ground state. The linear Stark shift increases the position of the cutoff. Harmonic spectrum contains both odd and even and non-integer harmonics of laser frequency. The explanation is in additional frequencies for the considered problem: (1) the inverse time of laser pulse duration, (2) vibrational frequencies of perturbed nuclear motion during the dissociation process. The extended plateau and the sharp cutoff in harmonic spectrum has been found. The height of the plateau and the cutoff increase with laser intensity. Results are compared with previous derivations [2-3]. This work was supported in part by Russian Foundation for Fundamental Investigations (grant N 99-02-17810).

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2.60 V. V. Suran, poster

Direct two–electron mechanism of doubly–charged ions formations: resonant structure of A^{2+} yield

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The number of previous investigations showed that the formation of doubly-excited ions (A^{2+}) during ionization of alkaline-earth atoms in strong laser field could be the result of two mechanisms: step-wise and direct two-electron ionization. When direct two-electron mechanism is realized, doubly-charged A^{2+} ions are formed in result of simultaneous detachment of two electrons directly from neutral atom [1, 2]. When this mechanism takes place, the formation of A^{2+} ions has considerably higher efficiency than under the step-wise mechanism realization. This mechanism is comparatively more difficult and in contrast to the step-wise mechanism the peculiarities of its realization are not studied in details yet.

Therefore, we had performed the cycle of detailed experimental investigations of the process of doubly charged ions formation under the influence of IR laser radiation on Sr and Ba atoms. We used the radiation of tunable laser on color centers (w = 8400-9000 cm^{-1}). We measured the dependence of A^{+} and A^{2+} yields on frequency of laser radiation at different field strengths of this radiation (E = 106-107 V/cm). It was determined that the yield of A^{2+} ions is only 2-3 orders smaller than A^{2+} ions yield.

In the A^{2+} yield in this case a number of resonant maxima are observed. On frequency scale these maxima are deposited in the vicinity of frequencies corresponding to one-photon transitions between excited states of neutral Sr and Ba atoms. The manifestation of these maxima could be explained by excitation of neutral atoms strongly perturbed in result of ac Stark effect. These maxima in A^{2+} yield manifest only in the case when the perturbation of corresponding states is such that its crossing with other less perturbed states takes place.

According to these experimental facts we propose following model for direct two-electron mechanism of doubly-charged ions formation. First of all population of strongly perturbed states takes place and then in result of variation of laser field strength the remission of perturbation of these states takes place. This populated state must cross the unperturbed states and at the same time the rebuilding of electron shell should be realized. The coupling of two electrons with core in this case will be weakened. The influence of laser radiation on the atom under such conditions leads to simultaneous detachment of two electrons directly from this atom.

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2.61 V. D. Taranukhin, poster

High-order Harmonic Generation by Multielectron Atoms with Laser Standing Wave of Relativistic Intensity

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We propose to use high field (HF) standing (S) wave for pumping multielectron atoms to obtain the shortest wavelength (SW) generation under tunnel above-threshold ionization (ATI) of multicharge ions. Such ions can "survive" to the moment when instantaneous pump intensity I(t) reaches the peak value I0 and can generate the SW radiation with frequency $\Omega = N\omega \sim I_0$ (ω is the pump wave frequency, N is the cut-off harmonic number). In traveling (T) wave of relativistic intensity I0, considerable restriction on the HHG efficiency arises due to longitudinal (relativistic) drift of photoelectron away from the parent ion. In S-wave, the magnetic field (responsible for the relativistic drift) is suppressed near the antinode points of electric field.

Fig. 1 shows the results of a "simpleman" analysis for HF ATI of Ar^{7+} ion with S- and T-waves of wavelength $\lambda = 0.3\ \mu m$. For S-wave, the results for three points along a wavevector direction are shown: $\epsilon = 4z/\lambda$ is the relative distance from the maximum electric field point where magnetic field amplitude is zero and relativistic effects are completely suppressed. For T-wave, though N continues to grow beyond the intensity $10^{17}\ W/cm^2$, the efficiency of cut-off generation essentially decreases as such generation occurs at not optimal ionization phase.

For S-wave, dependence $\Omega \sim I_0$ is valid for arbitrary intensities I_0 at $\epsilon = 0$ (making possible X-ray generation with $\Omega \sim 1 - 10 keV$). For other ϵ, magnetic field suppresses the cut-off frequency growth. However, it remains high enough for $\epsilon = 0.1 - 0.2$. This means 10 - 20 % efficiency of "utilizing" S-wave pump radiation. Fig. 2 presents the SW spectra (calculated with the quantum mechanical code) for HF ATI of Ar^{7+} ion with T- and S-wave pumping ($I_0 = 4 \cdot 10^{17}\ W/cm^2, \lambda = 0.3 \mu m$) that confirm these conclusions.

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2.62 V. D. Taranukhin, poster

Relativistic Ponderomotive Forces in Electromagnetic Field of Arbitrary Strength

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We discuss new features of ponderomotive forces in superstrong electromagnetic fields acting on: 1) above-threshold photoelectrons born inside the laser beam, 2) free electrons crossing the laser beam. The theory of such processes is developed for slightly inhomogeneous laser radiation without any limitations on laser intensity. The calculations performed similar to Gaponov-Miller approach. General expression for the ponderomotive force in the laboratory reference frame is

$$\vec{F}_L = \vec{F}_0 + \left[(\gamma - 1)/V_0^2\right] \left(\vec{F}_0 \vec{V}_0\right) \vec{V}_0 , \quad \gamma = \left(1 - V_0^2/c^2\right)^{-1/2},$$

$\vec{V}_0$ is the velocity of electron oscillation center, $\vec{F}_0$ is a cycle-averaged force acting on electron in co-moving ($\vec{V} = \vec{V}_0$) reference frame expressed in terms of field parameters in the laboratory system.

For linearly polarized spatially inhomogeneous laser radiation, it has been found that the force $\vec{F}_0$ in addition to usual gradient part $-c^2\nabla m^*$ (m^* is an electron effective mass) contains a vortex part with components along 1) the field wave vector $\vec{k} \parallel \vec{x}$: $\Delta F_k \sim \partial m^*/\partial x$ and 2) the electric field polarization $\vec{e} \parallel \vec{y}$: $\Delta F_e \sim \partial m^*/\partial y$. The vortex part contains all even powers of electric field amplitude E_0 and tends to zero at weak fields. In ultrarelativistic case $\Delta\vec{F}_e \lll \Delta\vec{F}_k$ and only $\Delta\vec{F}_k$ essentially contributes to $\vec{F}_0$. For circularly polarized field $\Delta\vec{F}_e = \Delta\vec{F}_k = 0$, and the force $\vec{F}_0$ keeps a gradient form: $\vec{F}_0 \sim -c^2\nabla m^*$.

In pulse plane wave, the electron feels the ponderomotive forces at front and trailing edges of the pulse. In this case, $\vec{F}_L = -\nabla U_p^*$ where U_p^* is a ponderomotive potential with effective electron mass m^*. A new kind of stabilization has been found for the ionization of multicharge ions by superintense ultrashort pump pulse due to the force $\vec{F}_L$. On the trailing edge of the pulse this force is able to compensate the relativistic (forward) drift of photoelectron away from the parent ion. And due to Coulomb attraction, it is possible to photoelectron be captured back to the closed orbit after the pump pulse is over. Such ("gradient") stabilization is essentially different from the known dichotomy, interference and Stark stabilizations.

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2.63 K. T. Taylor

Laser-Driven Few-Electron Atoms and Molecules

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Rapid developments in high-intensity laser technology over the past decade has provided experimentalists with a source of polarized monochromatic electromagnetic radiation with which to violently agitate even the innermost electrons of an atom or molecule. The violent interaction takes place over such a short time scale ($\sim$ 20 fsec) that the wavefunction for the atomic electrons evolves quickly and has no opportunity to be dominated by any stationary character. Thus the theorist is presented with an opportunity to study atomic electron dynamics far from equilibrium. Electron-electron interactions and, for laser intensities greater than $10^{18}\mathrm{W/cm^2}$ relativistic effects, play a very different role than in stationary atomic processes (electron-atom scattering, for instance) since now there is no longer infinite time for interactions to be equilibriated. Helium, with just two electrons, is the simplest atom where electron-electron interaction comes into play. We have embarked on a theoretical/computational study of the response of this atom to a high-intensity, linearly-polarized laser pulse. With such a pulse, the electronic motion has just 5 degrees of freedom - the overall component of angular momentum along the polarization direction is still conserved. The foundation of our study [1-3] has been to integrate directly the time-dependent Schrödinger

equation for a wavefunction solution that spans all five spatial dimensions i.e. both electrons of the atom are treated on an equal footing. Developments are in hand to extend these methods to the H_2 molecule, taking dissociation into account. We report progress in the following areas:

- New methods for distinguishing and separately calculating sequential double ionization and non-sequential double ionization.
- Success in generalizing the numerical methods and the parallel codes to handle the laser-driven H_2^+ molecule.
- High reliability and high accuracy calculations of 2-electron ionization rates, and verification of accuracy through comparison with R-Matrix Floquet calculations.

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2.64 Cs. Tóth

Ultrafast coherent and incoherent X-ray generation by inner-shell atomic processes induced by < 25 fs, > 1 J pulses of high power CPA lasers

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The development of keV X-ray lasers based on inner-shell atomic transitions [1,2] requires extremely fast energy deposition on a target in order to compete with the inherently fast (0.1-20 fs) atomic decay processes. The duration of ultrahigh peak power laser systems is now reaching this time scale [3]. We present here 1) the description of a state-of-the-art chirped pulse amplification (CPA) laser system capable to deliver > 1 J optical energy in less than 25 fs with 10 Hz repetition rate; and 2), the analysis of a new inner-shell X-ray laser scheme based on fast Coster-Kronig decay processes.
1) Our 10 Hz repetition rate CPA laser system consists of a 2 nJ, 15 fs Ti:sapphire oscillator, cylindrical mirror expander, and three Ti:sapphire amplification stages followed by a hybrid vacuum-atmosphere compressor. The 1.3 J compressed pulses are characterized by a low-dispersion, single-shot, PG-FROG setup, showing typical pulse duration of 23 ± 1.5 fs. Photoionization experiments in the optical tunneling regime have been performed to better asses the focused peak intensity in the order of 10^{20} W/cm^2. The laser system has effectively been used to produce high-brightness,

narrow-linewidth incoherent X-rays optimal for time dependent X-ray diffraction studies [4].
2) Further possible application of the high power, ultrafast laser system described above is the excitation of Coster-Kronig mediated inner-shell X-ray lasers. Such systems have inherently short lower level lifetimes and under certain conditions can be inverted both with excitation by energetic electrons as well as X-ray photons. For appropriately chosen atomic species and transitions, the population inversion between inner-shell hole states can be created by electron collisional ionization only - a situation which has previously been considered impossible. The L_2M_1 transition for Z=22 to 32 is the most robust to detrimental collisional processes [5]. Transient population inversion of 2.4x10^{19} cm^{-3} at 3.09 nm wavelength in Ti could be achieved for an electron pulse of 5 fs. Such electron pulses can be created by direct optical tunnel ionization in $> 10^{16}$ W/cm^2 intensity laser fields. Photoionization inner-shell pumping schemes will also benefit from the usage of this type of transition. Threshold conditions for incoherent X-ray pumping, conversion efficiency of visible laser photons into a desired X-ray bandwidth [2], and a design of sandwiched multilayer target structure will also be discussed.

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2.65 Zs. Tóth

Reflectivity transients on solid surfaces induced by 0.5 ps high power excimer laser irradiation

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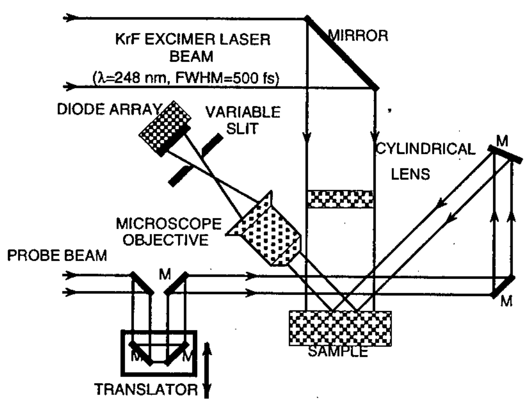

Changes in reflectivity of various solid materials upon irradiation with high power (10^{12}W/cm^2) ultrashort (480 fs) KrF excimer laser pulses are reported. The excimer pulse is focused by a cylindrical lens onto a line at the sample surface while a tilted wavefront (45°) probe pulse (λ=496 nm, 480 fs pulse length) is scanning over the ablating surface area (see Figure). Thus the spatial distribution of the reflected probe pulse corresponding to the temporal reflectivity transient, was recorded. For polymeric and semiconductor samples the reflectivity increases with a factor of 1.5-2 compared to the original value within a picosecond as the excimer laser pulse impinges onto the surface. It is shown that increasing the absorption of PMMA samples with naphthalene doping leads to an increase in maximum reflectivity. In case of glass reflectivity decrease is observed. The reflectivity increase or decrease is interpreted as a competing process of formation of high density free electron gas due to fast ionization processes, which leads to higher reflectance, and expansion of the ablation plume which leads to reflectivity decrease due to light scattering processes.

2.66 C. Trump, poster

Probing strong field photodissociation of H_2^+

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We investigate the decay of H_2^+ in high intensity ultrashort (30 fsec) light pulses by using a pump-probe technique. In a first intense pump pulse (wavelength: 795 nm) H_2 is photoionized. This pulse also initiates photodissociation of H_2^+. A representative angle resolved kinetic energy distribution of H^+ ions emitted along the direction of polarization of the light is shown in Fig. 2a (light intensity: $\approx 7 \times 10^{14}$ W/cm^2).

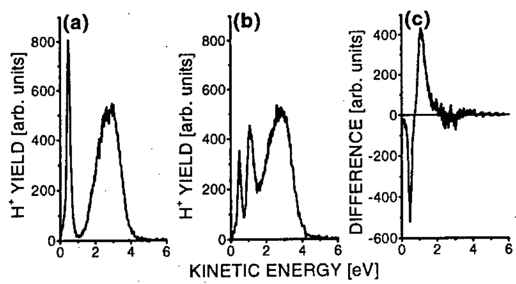

Figure 2: H^+ ion kinetic energy distributions taken (a) with the pump laser pulse alone, (b) with pump and probe pulse present (delay: 70 fsec). (c) the difference between the pump-probe and pump spectrum.

We observe H^+ ions from effective two photon dissociation of H_2^+ (the 0.5 eV line in Fig. 2a) and from Coulomb explosion of H_2^+ after further photoionization during dissociation (the broad line centered at ≈ 2.7 eV). Adding a probe pulse with a delay of (70 ± 13) fsec and an intensity equaling that of the pump pulse but polarized perpendicularly with respect to the pump light gives rise to the kinetic energy distribution in Fig. 2b. One additional line appears in this kinetic energy distribution with center at ≈ 1.1 eV. The position and shape of this line depends on the pump-probe delay time. A highly stable 1 kHz repetition rate laser system used for this investigation allows us to determine the ion yield redistribution induced by the probe light pulse quantitatively by subtracting the yield in Fig. 2a from that in Fig. 2b. The result is shown in part (c) of the figure. It is clearly seen that the effective two photon dissociation line decreases strongly with the probe pulse present. This and the kinetic energy of the ions in the new line in the pump-probe spectrum indicate that probe pulse photoionization of H_2^+ molecules dissociating in the effective two photon dissociation channel is responsible for the new line in Fig. 2b. We also find a small influence of the probe pulse on the Coulomb explosion line (at ≈ 2.7 eV) which increases with decreasing delay time (Fig. 2c).

2.67 V. I. Trunov, poster

Formation of ultrashort optical pulses in lasers with ultrawide complex gainband

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At present time the duration of the shortest optical pulses, generated in solid state tunable lasers, are restricted, in main, by gain bandwidth. New active media with more wider gainband, than for Al2O3:Ti3+ crystal, are needed .In our work we investigated the generation of ultrashort pulse (USP) in laser with composite active medium, consisting of several laser active centers with overlapping gainbands in common resonator [1]. It may be set of wideband active medium, a number of color centers or ions in common host, set of semiconductor lasers. This opens the possibilities to create ultrawide gainband and allows at optimum conditions, be advanced into subfemtosecond time scale range. In all this cases the gain contour have complex shape with local extrema.

The numerical simulation of the dynamics of formation USP at passive self-modelocking by noninertial saturated absorber (based on the Kerr nonlinearity) in laser with complex gain contour, has been performed. Areas of laser and nonlinear-optical parameters of active media, including into the composite medium, necessary for generation as single pulse on axial period with duration, determined by combined gain bandwidth, so as the train of USP with varying ultrahigh repetitions rates have been determinated. The dependence of the stationary mode achievement time of USP generation upon the main parameters of laser (gain, passive losses, Kerr nonlinearities, the depth of the hole in the non-saturated gain contour) was investigated. Strong influence of saturation intensity relation of active media, including into the composite medium on formation dynamics and extremal parameters of generated pulses has been discovered. It made possible of considerable increasing of gain bandwidth even in the case of using two active media with different saturation parameters in laser cavity.

On the base of performed model, combinations of active media, mostly available for experimental studies, are considered and analyzed. It has been shown, that composite active medium on the base of NaCl:F2+,YAG:Cr4+, Mg2SiO4:Cr4+ crystals can allow to get an optical pulse with duration at one cycle with extremely high steepness of electromagnetic field. The possibility of using a composite active medium in the mode of multipass and regenerative amplifier has been explored.

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2.68 S. Varro, poster

Generation of x-rays by irradiating metal surfaces with a powerful laser beam in presence of a strong static electric field

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We investigate the generation of high energy x-ray pulses by irradiating metal surfaces at grazing incidence with a powerful laser beam in the simultaneous presence of a strong static negative voltage in order to explain experiments by Farkas et al (Opt Commun **21** 408 (1977) ibid **67** 124 (1988)). Using the dipole-layer model proposed recently to describe the multiphoton photo-effect at metal surfaces (Phys Rev A **57** 663 (1998) J Phys D Appl Phys **30** 3071 (1997)) we are able to explain the essential features of the above process, in particular its dependence on the strength of the applied voltage and on the power of the used laser field as well as the maximum photon energy emitted. We also present on the basis of our model an estimate of the power of the emitted x-rays in fair agreement with the experimental data.

2.69 V. Véniard

A simple model for harmonic generation from atomic cluster

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High order harmonic generation by atoms irradiated by a strong infrared laser appears as a source of coherent XUV radiation with interesting coherence and brightness properties. It was proposed recently that atomic clusters can also be a source of short-wavelength radiation, providing in some cases harmonic yields higher than those produced by equivalent atomic targets [1]. However, no general picture has emerged about the relative efficiency of clusters as compared to atoms.

We have addressed the question of the response of an atomic cluster to an intense laser pulse by numerically solving the Time-Dependent Schrödinger Equation for a simplified one-dimensional system. We shall present the results of our analysis for the generation of high-order harmonics of the laser frequency and for the ionization dynamics of the atoms within the cluster for very short laser pulses.

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2.70 D. F. Zaretsky, poster

The time duration of high harmonic generation in the process of ATI

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The experiments performed during few last years show that the time duration of high harmonic generation [HHG] does not coincide with the pumping laser pulse duration.In all cases investigated the time of HHG is less or around 100 fsec and the pumping laser power is in the range $10^{14} - 10^{16}$ W/cm^2. The time of recombination of ATI electrons in the case of free atom is much larger. Therefore the HHG is a collective phenomenum and the phase matching of all emitters within the laser + atom interaction volume should be taken into account. To describe the HHG the quantum theory of radiation was applied. The formalism of this theory was generelised in the case of atomic system pumping by the powerful laser wave. The probability and time of HHG was calculated. This time was shown to be dependent on the pumping laser power, harmonic number,atomic density and ionisation rate. The numerical estimations performed for the real parameters of pumping laser power and atomic densities give a good agreement with experiment. The analogy between HHG and superradiance effect is discussed.

2.71 B. A. Zon

Many-particle aspects of tunnelling effect theory in atoms

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The familiar theory of the tunnelling effect in atoms (which is known as ADK theory) has essentially one-particle character. In this work two many-particle effects are considered which are supplementary to the ADK theory.
First, the calculations are performed for the simultaneous (during one half-period of the field oscillation) tunnelling of several electrons belonging to the same atomic shell. The corresponding Schrödinger equation can be solved in the parabolic coordinates. It is due to the fact that the N electrons interacting with an external field in dipole approximation can be treated as a single quasiparticle whose charge is Ne and the mass is Nm_e. The expression obtained for the tunnelling probability has the form used in the ADK theory, but it involves some effective principle quantum number for the tunnelling electrons which coincides with the empirical value proposed in the ref. [1].

The second effect considers a possibility of a cascade removing of several electrons from an atom, when the resulting ion occurs in an excited state. A detailed description is given for the case of two-electron ionisation of atoms with the closed s-shell. When the ion excitation energy is much less than the ionisation potential of the neutral atom, the obtained general formalism is reduced to the well-known sudden approximation. For numerical examples, some calculations are performed for Zn, Sr and Cd atoms.

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3 Laser spectroscopy

3.1 E. V. Baklanov

High precision calculations of the low-lying energy levels of the three body Coulomb system.

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Three-body Coulomb system plays an important role in the general theory of many particle problems. Energy level is expressed as the sum of the three terms: the nonrelativistic energy, the lowest order relativistic correction, and the Lamb shift, which includes the quantum electrodynamics corrections and the higher order relativistic terms. Precision, energy levels of the nonrelativistic problem will be found with, determines the volume of all subsequent calculations, i.e. the corrections to be taken into account. Therefore it is very important to develop a good method for high precision calculation of the nonrelativistic problem.

In this paper we have developed a method of calculation of the nonrelativistic eigenvalues and wave functions of a three body Coulomb system with arbitrary masses of the particles. The Pekeris method [1] is extended to the case when the mass of one particle is not infinitely heavy. The difference between this method and the previous work [2] is the introduction of the scaling parameter k. By choosing the appropriate value of this parameter, we can significantly increase the convergence of our method and, thus, obtain more precise results.

The developed method is used to calculate the energy levels of various three-body systems: low-lying helium energy levels; ground states of the negative positronium and hydrogen ions, positive ion of the hydrogen molecule. We have compared these results with various precision calculations [3-7]. The accuracy of our calculated nonrelativistic energies is 1-2 order of magnitude better in comparison with the previous calculations.

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3.2 W. Chen

A Widely Tunable Difference-Frequency Spectrometer for High-Resolution Infrared Laser Spectroscopy

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A continuous-wave (cw) difference-frequency generation spectrometer is developed for use in high-resolution infrared laser spectroscopy. Broadly tunable cw laser-based infrared source was generated from 8 to 19 μ by laser difference frequency mixing in a gallium selenide (GaSe) crystal. High-resolution spectra of Acetylene (C2H2) in the ν_5 band and Benzene (C6H6) in the ν_4 band have been scanned near 730 cm$^-$1 and 660 cm$^-$1, respectively, for molecular line parameters study. For environmental trace gas monitoring by laser absorption spectroscopy, high spectral purity and wide frequency tunability of cw laser source offer advantage not only for high selective, but also for high sensitive spectroscopic measurement in the mid-infrared region. Optimal compromise between higher line strength for high sensitive trace gas detection and maximum discrimination from lines overlapping for high selective measurement was investigated by trace constituents measurement of C2H2 and C6H6. Recent experimental results will be reported.

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3.3 G. Djotyan

Interaction of frequency-chirped bichromatic laser pulses with multilevel atoms: Writing and storage of optical information

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We consider in this paper interaction of frequency-chirped bichromatic laser pulses (BLP) each being superposition of two pulses of a same shape with different carrier (and, in general different Rabi) frequencies with three- and four- level quantum systems. We show that population transfer in these quantum systems is sensitive to the relative phases and relative amplitudes of the pulses forming BLP. We propose to use this sensitivity for coherent, fast and robust storage and processing of the optical phase or intensity information as well as for spectroscopic applications and constructing of a phase-selective atomic beam-splitter.

In the case of the Λ atom with two ground states coupled to a common excited state, each pulse of the BLP couples one of the ground states to the common excited state.

If the BLP's pulses are of identical shape and chirp, the system under consideration is equivalent to a two-state system consisting of a "bright" superposition of the ground states which is coupled to the excited state by the laser field and of the "dark" superposition of the ground states which doesn't interact with the laser field. As is well known, a frequency-chirped laser pulse produces complete transfer of populations between the states of a two-state atom in the adiabatic passage (AP) regime. In our case, the frequency-chirped BLP produces complete population transfer from the "bright" superposition to the excited state leaving unchanged the population of the "dark" superposition. Since the "bright" and "dark" superposition states depend on the relative phase and relative strength of the pulses forming BLP, the phase and intensity information contained in the BLP are transferred to the excited state with the population of the "bright" state or are written in the population of the "dark" superposition in the ground state. This information writing is produced by BLP with duration much shorter compared with the atomic relaxation times. The storage of information is produced in a second step by a subsequent frequency-chirped laser pulse which in a fast way transfers the population of the excited state (with the information written therein) into one of the nondecaying state of the atom. Reading of the stored information may be produced by acting by the same frequency-chirped laser pulse, which transforms the information into the population of the excited state. The latter may be detected for example, by analyzing the spontaneous or stimulated emission from this state.
It is worth noting that the scheme considered in this paper may be used also for *fast* and *robust* generation of an arbitrary coherent superposition of the ground states of the Λ atom by controlling the relative phase of the BLP's pulses, which may find several applications in quantum optics.

3.4 A. E. Dudelzak

Progress in ORACLE (Ozone Research with Advanced Cooperative Lidar Experiment): Joint NASA-CSA development of a space-based ozone dial

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ORACLE is a joint NASA / CSA development of a fully automated differential absorption lidar (DIAL) for global measurements of tropospheric and stratospheric ozone / aerosols with high vertical and horizontal resolution. The paper overviews the progress in ORACLE during the last two years. The joint team of the NASA Langley Research Center (LaRC) and of the Canadian Space Agency (CSA) have been carrying out R&D on ORACLE since 1995. Researchers and engineers of other NASA Centers, Canadian Departments, US and Canadian industries, and of the Russian Vavilov State Optical Institute also participate in the study.

Key issues of demonstrating novel technologies, allowing such a mission, and of obtaining scientific data from spacecraft have been addressed. ORACLE's delivered data will answer the needs of studying the depletion of stratospheric ozone, global warming, atmospheric transport and dynamics, tropospheric ozone budgets, atmospheric chemistry, and the atmospheric impact of hazards. Only a space-based laser system can achieve the required spatial resolution for ozone and aerosols in both the stratosphere and the troposphere on a global scale at all altitudes. The scientific needs for such a project have been recently reviewed by an independent Science Advisory Group of Canadian and US atmospheric scientists.
During the last two years, ORACLE's team has significantly progressed in developing both hardware and software associated with all key lidar subsystems and data acquisition/processing. The most novel technologies are employed in ORACLE: an all-solid-state UV laser, photon-counting detectors, and an ultra-lightweight, space-deployable telescope. Two laser concepts have been investigated and prototyped in parallel - a tunable, OPO - based scheme, and the multi-step, phase-conjugated Raman-shifting / Brillouin conversion approach. The concept development and the engineering analysis of a 2m-deployable reflector with a two-stage adaptive optic corrector have been completed. The secondary optical module, the spectral filtering and the photon counting detector units have been prototyped. The paper overviews in detail the results of these developments.

3.5 J. H. Eberly

Quantum phase lock in Rydberg atoms

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Quantum states of a Rydberg atom can be localized in space due to dressing by a resonant microwave field. The effect of the localization is the quantum analog of the phase lock effect in classical mechanics, when classical motion in phase space becomes trapped in a nonlinear resonance.
We investigate analytically and numerically several types of locked quantum states - from states localized near certain classical trajectories in the rotating frame to fully localized wave packets moving around the nucleus along elliptic orbits.
We also discuss the possibility of controlling localized quantum states through control of the dressing microwave field parameters. Our calculations show that quantum control via quantum phase lock is a promising method for adiabatic transfer of population between Rydberg states with various principal quantum numbers and angular momenta.

This work was supported in part by NSF grants PHY-9304335 and PHY-9415583, and CRDF grant RP1-244.

3.6 U. Hinze

Resonant CW Four-Wave Mixing and Parametric Amplification

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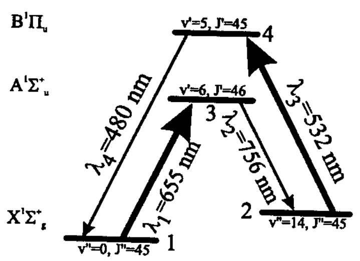
We report on CW resonant four-wave mixing and a first experimental demonstration of parametric amplification in a double-Λ level configuration.
In a double-Λ scheme two pump-fields λ_1, λ_3 realize a coupling between the levels 1-3 and 2-4. The second field λ_2 is operated as a Stokes-type Raman laser (pump-field λ_1). The field λ_4 is generated by a four-wave process according to $\omega_4 = \omega_1 - \omega_2 + \omega_3$. Our theoretical analysis shows that parametric amplification is possible for the fields 2 and 4 in addition to the Raman gain for field 2. Under suitable conditions this Raman gain can be transferred to the fourth field.



Experimental investigations have been performed in Na_2-molecules (see Fig.). In a recently realized scheme with pump-fields λ_1=655 nm (200 mW) and λ_3=532 nm (150 mW), the fields λ_2=756 nm (20 mW) and λ_4=480 nm are generated. For λ_4 a maximum power of 2 mW has been achieved so far.
Using very weak amplitude-modulated fields λ_2 and λ_4 parametric gain has been measured for λ_4 and the transfer of Raman gain has been demonstrated.

3.7 A. N. Kireev

Double-mode He-Ne and diode-pumped RbCl:Li/FA(II) lasers for precise measurements in the 3.0 - 3.4 μm region

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State of the art, recent applications in fundamental metrology, and likely developments of double-mode He-Ne and diode-pumped RbCl:Li color center lasers (CCL) are presented.

These lasers stabilised over supernarrow saturated dispersion resonances of the lines in ν_3 vibration - rotational methane band (3.2-3.4 μm) are prospective for creation of the transportable optical frequency standards (TOFS) with reproducibility and repeatability 10^{-13} - 10^{-14} which in turn can play an important role in optical fundamental metrology and precise spectroscopy. Being calibrated at a radio-optical frequency chain with respect to Cs primary standard such kind of TOFS can disseminate with the uncertainty 10^{-13} the absolute value of its carrier frequency (88 THz) and can be used in laboratories interested in building an accurate IR - visible frequency grid. This way to avoid the problem of a cumbersome low frequency part (10^{10} Hz to $10^{1}4$ Hz) of the phase-coherent radio-optical frequency chains seems to be attractive particularly now when cw powerful (400 mW) optical parametric oscillators (OPO) appeared in the mid-IR range (3.0 - 4.0 μm). OPO phase locked to the TOFS frequency can overcome the problem of relatively low output intensity (1 mW) of the TOFS and make much easier nonlinear mixing and transformation of the 88 THz radiation.

The present paper considers recent progress with a new version of the transportable He-Ne/CH4 OFS and presents the results of the investigations of the physical reasons influencing methane dispersion resonance lineshape. As a result of absolute frequency measurements with a set of He- Ne/CH4 TOFS (developed in Lebedev Institute) at radio- optical frequency chains of PTB (Braunschweig) and BNM/LPTF (Paris) the following parameters of the TOFS were established: a) frequency reproducibility (for different devices) 10^{-12}; b) frequency repeatability (for one device during several months) $2*10^{-13}$; c) frequency stability (for averaging time 10^3 s) 10^{-14}.

Next development of the methane OFS is possible via usage the transitions from the lower rotational levels. Thermal cooling (down to 77K...40K) of a methane cell leads to 102-103 times increasing of the absorption coefficient. In combination with detection of slow molecules it allows to realise a compact transportable CH4 OFS with reproducibility and accuracy 10^{-15}. First experiments with a double-mode LD-pumped RbCl:Li CCL with an intracavity methane absorption cell have been performed and saturated dispersion resonances on the R-branch ν_3-band methane lines were observed.

3.8 N. Konopleva, poster

Magnetically induced amplification without inversion in three-level cascade scheme

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Phenomena of amplification without inversion (AWI) is well studied in three-level Λ, V and cascade atomic systems [1]. In all this schemes AWI is arisen from coherent effects induced by a strong coherent field (driving field). In the present work we propose a scheme for LWI in which a broadband optical field is used. The field width is much broader than the natural width, Rabi frequencies and other characteristics of atomic transitions.

We consider a probe field propagation in a medium of open three-level cascade atoms $J_0 = 0 \to J_1 = 1 \to J_2 = 0$. A lower level with $J_0 = 0$ is taken to be the ground one. A transition $0 \to 1$ is excited by a broadband linearly polarized field. We suppose, that there is an incoherent pump causing to population transfer from the level $J_0 = 0$ to the exited level $J_2 = 0$. A probe field is resonant to a $1 \to 0$ transition. The probe field propagates in the same direction as the broadband field. A static magnetic field orthogonal to the wave vectors of the light fields and polarization vector of the broadband field is applied. We consider a field driving a $0 \to 1$ transition as a Gaussian-Markovian random process with a bandwidth of the noise, much broader, then the natural widths of the levels, Raby frequencies and Zeeman splitting. Under this condition interference effects giving rise to AWI in cascade system, when the lower pair of atomic levels is exited by the coherent field, are absent. We obtain that one of the normal waves of the probe field can amplify in the absence of inversion between any sublevel of the $J_1 = 1$ level and the upper excited level. In the scheme under consideration AWI is connected with Zeeman coherences of intermediate level $J_1 = 1$. This coherences are generated by the broadband field together with the magnetic field. Such effect was studied for two-level degenerated atoms [2]. We have shown that the origin of amplification in this case is analogical to one in Λ scheme [3].

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3.9 T. G. Mitrofanova, poster

Accumulated long-lived photon echo in the Van-Vleck paramagnetics and problem of optical memory

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The physics of the accumulated long-lived photon echo (ALPE) is investigated experimentally and theoretically. The use of ALPE in optical memory devices was studied. A comparison of the theory with experimental data in the Van-Vleck paramagnetics

made it possible to estimate the relaxation rates of a populations of the hyperfine sublevels of ground state and to assess the nonstability of an optical delay line in experimental setup. This report is devoted to the accumulated long-lived photon echo (ALPE) and its applications in the optical echo-spectroscopy and in the phase memory devices. The results of the experimental investigations of ALPE in the LaF3:Pr3+ crystal are discussed in details. Multipulse regimes of optical excitation are quite promising for the elaboration of optical memory devices using the long-lived photon echo. Our investigations show that information may appropriately be written in the regime of ALPE. First, this makes it possible to increase the echo intensity without augmenting the intensity of pumping pulses. Secondly, the accumulated regime may be used for multibit data writing and reading in optical memory devices. Thirdly, multichannel writing is possible in an accumulated regime, when each object pulse has its own wave vector. This variant of data writing may be used both for increasing memory capacity and for space (mulichannel) exchange of information with the optical memory device.

3.10 Á. Mohácsi

High stability external cavity diode laser system for photoacoustic gas detection

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Photoacoustic gas detection technique reached its biggest popularity in the seventies and eighties by using it with combination of light sources such as CO and CO_2 lasers. However these systems were finally found impractical due to the complexity of the applied light sources. In the recent years photoacoustic gas detection is again getting a new momentum due to the application of various diode laser light sources. This next generation of systems are simple, relatively cheap and capable of automatic operation. However the final spread of this technique is largely depends on the quality of the applied diode laser light sources. We have developed external cavity diode laser (ECDL) light sources with reasonable output light power ($>$ 1mW), large range of continuous tunability ($>$ 200 GHz) and improved stability. Especially this latest feature has its importance as for spectrally resolved measurement of ro-vibrational lines of gaseous materials with small atomic number the laser wavelength has be stable up to the seventh-eight digit requiring the use of specially designed mechanics for the laser cavity. In this work we present our ECDL system, compare it with commercially available ECDL systems and show ist application for photoacoustic gas detection. Also the effect of laser instability on the photoacoustic gas detection method is studied experimentally.

3.11 T. Nagy

Spectral evolution of short pulses in KrF amplifiers

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Nowadays short pulse KrF amplifiers are most frequently used as a final stage of high intensity laser systems operating in the UV. KrF modules allow the efficient amplification of sub-ps pulses in a direct way (without using the CPA scheme) because of the limited saturation energy density of the active medium. However, saturated amplification in the amplifier and the propagation of the short pulse through the laser windows lead to moderate nonlinear effects that can influence the spectrum of the amplified pulse.

Experiments were carried out in order to study the spectral changes of short pulses during the amplification in a 3-pass KrF amplifier. 500 fs frequency doubled UV pulses of a dye laser system [1] were sent into a prism compressor in which a variable (positive through negative) chirp was introduced by changing the compressor length. These chirped UV pulses were used as an input for the KrF amplifier. After 3 passes the autocorrelation curve and the spectrum of the amplified pulses were recorded. It was found that in the case of positively chirped input pulses the output spectrum was greatly broadened at the long-wavelength side. Decreasing the amount of the chirp the spectral broadening became less pronounced. When the input pulse was negatively chirped the output spectrum was even narrowed. This technique can be effectively used for enhancing or narrowing the spectral width of the short UV pulses in a controlled manner.

Numerical solutions of the pulse propagation equation in nonlinear media show that the effect is caused by the constructive or destructive interference of the initial chirp and the chirp introduced by the nonlinear effects during the amplification.

This work has been supported by the K+F program of the Hungarian Ministry of Education (contract FKFP 1103/1997) and by the OTKA Foundation of the Hungarian Academy of Sciences (contract T 029179).

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3.12 O. N. Prudnikov, poster

New friction force caused by spontaneous radiation pressure

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In a resonant light field forces on atom are caused by either induced or spontaneous radiation pressure. In the field of polarization-gradient cooling the induced radiation pressure is usually connected with an ellipticity gradient (e.g. $lin \perp lin$ configuration) and results in the Sisyphus friction [1]. At the same time the spontaneous radiation pressure arising from an orientation gradient (e.g. $\sigma^+ - \sigma^-$ configuration) gives friction due to the velocity-selective optical pumping of the ground-state Zeeman sublevels [1]. The common feature of all known friction mechanisms is the fact, that the friction force is an odd function of the field detuning. Then, at the exact resonance the friction vanishes.

In the present paper we consider one-dimensional field configurations, which has not been studied previously, where all possible gradients (ellipticity, orientation, phase, and intensity) are present. These field configurations are formed by two counter-propagating elliptically polarized light waves. The polarization ellipses have the same elliticity and opposite rotations and their major semiaxes make an arbitrary angle. For optical transition $j_g = 1/2 \to j_e = 3/2$, as an example, we find out that in such field configurations, apart from known friction forces, there exists new force. This force originates from the spontaneous radiation pressure and is based on the Sisyphus effect. In contrast to the known Sisyphus friction our force appears due to the spatially non-uniformity of the retardation. It is remarkable that new friction force is even in the detuning and does not vanish at the exact resonance. Note, the general time-inversion symmetry [2] does not forbid such a detuning dependence in the case under consideration. Here the direction of the kinetic process depends on the field configuration.

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3.13 N. N. Rubtsova

Polarization properties of the photon echoes in ytterbium vapor: dependence on the exciting pulses areas

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Experiments on photon echo in ytterbium vapor under action of pulsed dye lasers pumped by excimer lasers are performed with the aim to loock at polarization dependence of echo responses for various areas of exciting pulses. Comparison with theoretical predictions is made.

3.14 A. F. Semerok

Optical diagnostics system for measuring SUPER-ERIC plasma parameters

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Optical diagnostics is seen as an attractive and reliable non-disturbing means to measure plasma parameters. Laser induced fluorescence, laser absorption and the Fabry-Perot interferometry methods were applied to measure temperature and density of plasma of SUPER-ERIC installation (CEA Saclay, France). SUPER-ERIC is mainly used for isotope separation by ion cyclotron resonance (ICR) in the magnetic field of some Tesla.
The choice and optimisation of the optical diagnostics system were made with taking into account the preliminary study of new properties of cw-laser beam resonant interaction with highly magnetised ions [1,2].
The diagnostics system parameters as well as the measured BaII and GdII plasma parameters in the ion sputtering plasma source, in the ICR heating zone and near the ion collector are presented and discussed. The experimental results were in good agreement with the theoretical estimations.

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3.15 R. N. Shakmuratov

Locking and unlocking of the transient nutation signal

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A new method of the transient nutation signal locking for solids with inhomogeneously broadened absorption line is proposed. Usually this signal decays very rapidly with the rate of the order of $R = dE/\hbar$, where d is a dipole matrix element and E is a driving field amplitude. Decay of the transient nutation is caused by the polarization ringing at different frequencies spread around the driving field frequency ω by the Rabi

oscillations. The frequencies of the latter depend as $\sqrt{\Delta^2 + R^2}$ on the field tuning, $\Delta = \omega_i - \omega$, where ω_i is a resonant frequency of the i-th component of the absorption line.

It is proposed to lock an appreciable amount of the polarization in phase with the driving field in order to stop the ringing. This can be done by the $\pi/2$ phase shift of the driving field at the time T after the switching on the field. The durations T, when the locked polarization takes maximum values, are calculated. It is proposed also a procedure of polarization unlocking to produce a transient signal. The method can provide a direct measurement of the irreversible decay of the in-phase component of the polarization. This decay plays a dominant role in saturation broadening of the absorption line.

3.16 A. V. Sokolov

Subfemtosecond Pulse Generation by Molecular Modulation

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We propose and analyzes a technique for producing subfemtoseond pulses of radiation. The essence of this technique is the use of a Raman transition with a sufficiently large coherence that the generation length and phase-slip length are of the same order. When this is the case, the Raman spectrum is very broad and is generated collinearly. As initially generated, the spectrum has approximately Bessel function sideband amplitudes and FM phases, and in the time domain corresponds to a periodic frequency-modulated beatnote. As the waveform propagates, group velocity dispersion causes temporal compression into the subfemtosecond domain.

By numerically modeling this process in molecular hydrogen and deuterium, we calculate a generated train of pulses with a spectral bandwidth of 70,000 cm^{-1} and a pulse length of 0.22 fs. In the experiment, we demonstrate the collinear generation of a spectrum ranging from 2.94 μm to 195 nm and discuss possibilities for the ultrashort pulse measurements.

3.17 A. V. Taichenachev, poster

Simple theoretical model for electromagnetically induced absorption: Four-state N-atom

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As is well-known the nonlinear interference effects in the resonant atom-light interaction can lead to the electromagnetically induced transparency (EIT) of atomic medium [1] as well as to other interesting phenomena [2]. The key point of all these phenomena is the light-induced coherence between atomic levels, which are not coupled by dipole transitions. Recently Akulshin and co-workers have observed subnatural-width resonances in the absorption on the D_2 line of rubidium vapor under excitation by two copropagating optical waves with variable frequency offset [3]. Surprisingly that, apart from EIT-resonances with negative sign, they have detected positive resonances termed in [3] as electromagnetically induced absorption (EIA). Basing on the experimental results and numerical calculations, authors of ref.[3] have deduced that EIA occurs in a degenerate two-level system when the three conditions are satisfied: i) The excited-state total angular momentum $F_e = F_g + 1$. ii) Transition $F_g \to F_e$ is closed. iii) The ground state is degenerate $F_g > 0$.

In the present paper we propose a simple theoretical model for EIA – four-state N-atom. Remind that three-state Λ and V-systems give the EIT-resonances only. Namely, we consider an atom with four states $|i\rangle$, $i = 1 \dots 4$. The odd states $|1\rangle$ and $|3\rangle$ are degenerate and belong to the ground level, while the even states (also degenerate) form the excited level. All optical transitions $|odd\rangle \to |even\rangle$ are permitted except for $|1\rangle \to |4\rangle$, that is forbidden. The strong control field with frequency ω_1 drives the transitions $|1\rangle \to |2\rangle$ and $|3\rangle \to |4\rangle$. The weak probe at ω_2 is applied to the $|3\rangle \to |2\rangle$ transition. An analytical expression for the absorption as a function of frequency offset $\omega_1 - \omega_2$ is found. It is shown that EIA appears due to the spontaneous transfer of the light-induced coherence from the excited level to the ground one. Obviously, both Λ and V-systems do not describe such a process. The sign of the subnatural resonance depends on the branching ratio constant $0 \leq b \leq 1$ and becomes positive for closed transition $b = 1$. Velocity averaging in the case of Doppler broadening is briefly discussed.

It is worth noting, effects of the spontaneous coherence transfer on nonlinear resonances in the probe field spectroscopy have been considered for the first time by S. G. Rautian [4].

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3.18 A. V. Taichenachev, poster

Two-Dimensional Sideband Raman Cooling and $m = 0$ Zeeman State Preparation in an Optical Lattice

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Laser cooled atoms play a critical role in modern designs of frequency standards such as atomic fountains [1]. Recently, an elegant and efficient method of two-dimensional cooling to the vibrational ground state of a far-off-resonance optical lattice has been demonstrated [2]. This method is a variant of Raman sideband cooling based on the two-photon transitions between the vibrational manifolds of adjacent Zeeman substates. A static magnetic field is used to tune the Zeeman levels so that Raman resonance occurs on the red sideband and results in cooling. Two circulary polarized fields are used to recycle the atoms for repetative Raman cooling. Unfortunately, a direct application of this scheme to frequency standards meets with several difficulties. First, atoms are accumulated in the stretched $m = F$ substate of the $F = 4$ ground-state hyperfine level of Cs. For clock applications it would be necessary to transfer atoms from $|F = 4, m = 4\rangle$ to $|F = 4, m = 0\rangle$ without additional heating. In principle, this can be realized by the adiabatic passage technique. Second, in the cooling scheme of ref.[2] a static magnetic field in the range $100 - 300\,mG$ is used to produce the required energy shift of the Zeeman substates and, consequently, additional shielding of the Ramsey region of the clock is necessary. Finally and most critically, the geometry of the cooling scheme requires pumping and repumping orthogonal to the cooling plane and and these would, while present, produce unwanted light shifts for atoms in the Ramsey region.

Stimulated by the concepts and results from ref.[2], we propose a new variant of transverse sideband cooling, where the problems mentioned above are avoided, while still maitaining most of the attractive features. In the present scheme only cw lasers beams lying in the cooling plane are used. The basic difference from the method of [2] is that: the linearly polarized pumping field plays a two-fold role, providing both optical pumping back to the $m = 0$ magnetic sublevel and also causing a uniform ac Stark shift that replaces the external magnetic field induced Zeeman shift in [2]. The lattice and cooling parameters are studied in the framework of simple theoretical models. Apart from these, we find that coherence between degenerated lower vibrational levels can be important, leading to significant changes in the cooling efficiency and cooling time under certain conditions.

The proposed cooling method may be useful for atom optics as a high-brightness well-collimated source of atoms, or for general purposes of quantum-state control in a non-dissipative optical lattice.

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3.19 F. K. Tittel

Novel Diode Laser Based Sensors for Gas Sensing Applications

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The development of compact spectroscopic gas sensors and their application to environmental and biomedical sensing will be discussed [1]. These sensors employ mid-infrared difference frequency generation (DFG) in periodically poled lithium niobate (PPLN) crystals pumped by two single frequency solid state lasers such as diode lasers, diode pumped Nd:YAG, and fiber lasers. Ultra-sensitive, highly selective, and real-time measurements of several important atmospheric trace gases - including carbon monoxide, nitrous oxide, carbon dioxide, formaldehyde, and methane - have been demonstrated. In recent DFG work, the emphasis has been on improved sensor robustness against vibrations and temperature drifts by using optical fiber for beam delivery, combining, and amplification [2,3]. Furthermore, attention has been paid to using diode laser pump sources that are fiber coupled ("pigtailed"), or can be fiber coupled (using commercially available devices). Fiber pump delivery also facilitates the efficient use of the wise gain bandwidth of commercially available ytterbium and erbium doped fiber amplifiers. The use of diode-laser pump sources with desirable attributes such as inherent frequency stability and 2-50 mW power levels will be described. These include telecommunications distributed feedback (DFB) diode lasers that are readily available near 1.55 μm, distributed Bragg reflective (DBR) diode available near 1 μm, and broadly tunable extended cavity diode lasers (ECDL's). A DFG sensor, which is continuously tunable from 3.25-4.4 μm, has been successfully demonstrated. This device uses as pump sources an ECDL (20 mW, 814 to 870 nm) and a DBR diode laser (50 mW, 1083 nm) seeded Ytterbium doped fiber amplifier pumped by a 975 nm, 2 W diode laser. The e fiber amplifier boosts the seed pump power of 10 mW to 540 mW at 1083 nm. Both lasers are coupled into a single mode fiber and combined by a wavelength division multiplexer (WDM). The linear polarization output from the fiber for a e+e(r)e nonlinear mixing process in the PPLN crystal is maintained by using two polarization controllers in the fiber delivery system. Coarse tuning is achieved by rotation of the feedback mirror in the Littman type ECDL. Fine tuning and scanning of single or multi-component absorption lines of up to 25 GHz is accomplished by current modulation of the DBR diode laser (50 Hz). The sensor, including driver electronics, optics, and an 18 m path length multi-pass cell, was mounted on a breadboard (45 x 45 x 12 cm^3). An experimental conversion efficiency of 0.74 mW/W^2 at a wavelength of 3.5 μm was obtained using an achromatic imaging lens (M=3D11; 0.24 NA). This value compares favorably with a theoretical DFG conversion efficiency of 1.4 mW/W^2. Recent results with tunable mid-infrared quantum cascade lasers will also be reported.

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3.20 P. E. Toschek

Single-Atom Interferometry

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The phase shift of the hyperfine Larmor precession of an individual ground-state $^{171}Yb^{+}$ ion upon pulsed variation of the ambient magnetic field has been measured by microwave-optical double resonance interpreted in terms of Mach-Zehnder interferometry. So far, measurements on individual trapped particles have been restricted to internal or vibrational energies. Measurements on individual quantum system are accompanied by reduction of the quantum state and reveal the instantaneous value of the measured variable, not just an expectation value. Averaging over an ensemble of *individual measurements*, compared with measurements on an ensemble of ions, demonstrates quantum ergodicity. Even a single measurement yields (incomplete) phase information. On the peaks and dips of the interferogram, the results of measurements are *deterministic* (each try gives same result). This feature agrees with that of measurments on an ensemble. However, outside the peaks and dips of the interferogram, where ion probing is incompatible with ion preparation, the results of measurments are *indeterministic* (each try gives random result). This is demonstrated by laser-exciting an $^{172}Yb^{+}$ ion on the $E2$ line $S_{1/2} - D_{5/2}$.

3.21 W. J. Witteman

On the extension of the pulse length of a discharge excited ArF excimer laser

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The present study concerns the generation of long laser pulses of a discharge pumped ArF excimer laser ($\lambda = 193$ nm). The pulse length of a discharge excited ArF excimer laser is generally restricted to ~ 20 ns because of the growth of plasma instabilities, which cause arcing of the discharge and premature termination of the laser pulse. On the other hand, longer laser pulse lengths enable a better control of the optical quality of the laser, as well as an increase of the lifetime of the optics.

In order to obtain a good discharge stability and a long laser pulse a spatially homogeneous preionisation electron density is necessary. Using X-rays a homogeneous preionisation electron density of $\sim 10^9$ cm^{-3} is easily generated. To excite the laser

pulse the preionisation electron density must be increased to the breakdown level of $\sim 10^{14}$ cm^{-3} in a very short time, so that the possible growth of small-scale inhomogeneities into arcs is prohibited, while the ignited discharge is to be sustained at the steady state voltage for as long as possible. The best results are found by using a spiker-sustainer excitation scheme, with a voltage polarity reversal in the electron multiplication phase of the discharge.
We were able to achieve pulse lengths of up to 120 ns, which is approximately 6 times as long as usual for ArF lasers. The performance of the laser proves to be primarily dependent on the discharge stability, and therefore on the preionisation timing with respect to the voltage pulse, as well as on the gas composition and the pumping power. The optimum pulse length and the maximum pulse energy are obtained with different gas compositions, due to a trade-off between the discharge stability and the laser gain.

3.22 V. A. Zuikov

The spatial and spectral properties of the femtosecond photon echo and the angle echo-spectroscopy possibility

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The new method of the optical high-resolution echo-spectroscopy, named as the angle echo-spectroscopy , is grounded. In this method the angle between the directions of pumping pulses propagation is varied instead the changing of the carrier frequency of the excitation pulses. The regularities of the two-pulse photon echo generation in doped crystals under changes of the angle between directions of the laser pulses propagation are investigated theoretically. The experimental data on the picosecond echo-spectroscopy, obtained by V.Zuikov, U.Wild, A.Rebane et.al., are analyzed in details. The angular spectroscopy possibility is discussed. This report is devoted to investigation of the spatial and spectral properties of the femtosecond and picosecond photon echo in the doped polymer films. The shift of the photon echo spectrum relative to the excited pulses spectrum is observed when the angle between the wave vectors of excited pulses is changed. The new method of the optical high-resolution echo-spectroscopy, named as the angle echo-spectroscopy , is grounded. The samples consisted of polymer films activated with organic dye molecules and cooled down to liquid-helium temperature. The optical setup used for the excitation and detection of the femtosecond and picosecond photon echo is discussed in this report. The pumping pulses had a duration of 150-200 fs and spectral width of 9 nm. The angle between excited pulses was changed from 0 to 12 degrees.

4 Solid state lasers and nonlinear optics

4.1 P. Apai

Broad-band photorefractive phase conjugation in a dispersive scheme

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High power semiconductor lasers, tunable and fs vibronic lasers exhibit wide bandwidth and consequently low temporal coherence. Degenerative wave mixing in photorefractive (PR) crystals is suitable for the elimination of wavefront distortions and for beam cleaning, however, traditional schemes are restricted to monochromatic light sources of macroscopic coherence length. We report on experimental results which demonstrate that our novel disperse arrangement is well suited for photorefractive phase conjugation (PC) of broadband radiation emitted by CW and fs lasers.
The solution for white light interference fringe generation in PR crystals suggested by Cronin-Golomb can only be used for two-wave mixing at special crystal orientation [1]. Our scheme is applicable in more general since it does not suffer from such restrictions. The efficiency of the wave mixing process depends on the contrast and length of the index grating produced in the PR crystal. In order to improve the efficiency we dispersive the broadband laser beam perpendicular to the plane of propagation by a diffraction grating. The different spectral components appear spatially decomposed in the focal plane of a cylindrical lens, where the PR crystal is placed. Details of the experimental set-up and the first experiments were reported in [2].
In this paper we review our results in the CW regime and, for the first time we report on our PC experiments with fs pulses, too. The light source was a Ti-sapphire laser, and the second harmonic radiation generated in BBO. The photorefractive crystal was an undoped BaTiO3 used in "cat" self-pumped phase conjugation configuration [3]. The performance of the novel scheme was investigated in different conditions, and we observed efficient PC up to tenth of nanometers of spectral bandwidth.
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4.2 G. A. Bufetova

Analysis and modeling of the thermolens dynamical behavior in pulsed solid-state lasers.

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In the past few years it is seen the new interest to the processes of the heat deposition, dynamical heat generated distortions in the rods and their effect to the lasing characteristics of the solid-state lasers. This interest is mainly connected by the wide spread of the technological and medical applications of the 2- and 3-micm lasers. In former times the main attention was paid to the thermal effects investigation in the steady-state operation mode under the comparatively homogeneous pumping energy (and consequently heat generation) distribution over the volume of the active medium. In the paper we present the results of the modeling of the dynamical processes of the thermal lens progress in the active rods under the different conditions of the heat deposition. We discuss both the effects of the different types of pump cavities and the properties of the active media to the characteristics and temporal evolution of the thermal lens in the cylindrically shaped active rods in the non-equilibrium thermal regime of the lasing for the pulsed solid-state lasers. The results of the simulation are compared with the experiment. We show the influence of the dynamical thermolens to the damage of the optical elements mounted both inside and outside of the resonator.

4.3 P. B. W. Burmester

Type I noncritically phase-matched second harmonic generation in $Gd_{1-x}Y_xCa_4O(BO_3)_3$

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The new nonlinear materials of the $ReCa_4O(BO_3)_3$-family (Re = Rare earth) possess some distinguished properties, like high nonlinear coefficients and transparency in the UV. Furthermore they are nonhygroscopic, melt nearly congruently and can be grown in large sizes by the Czochralski technique. To combine the exellent properties of ReCOB with the advantages of noncritical phase-matching, i.e. large angular acceptance bandwidths and the lack of beam walk off, crystals have to be cut parallel to a main dielectrical axis. In z-cut crystals phase-matching can be realized with the polarisation of the fundamental and the second harmonic parallel to the y- and x-axis, respectively. The phase-matching wavelengths for the pure materials YCOB and GdCOB are 840nm and 966nm, respectively. In z-cut $Gd_{1-x}Y_xCOB$ the noncritical phase-matching wavelength varies in the range from 840nm to 966nm as the compositional parameter x is varied. Unfortunately, the corresponding nonlinear coefficient d_{12} is the smallest of the coefficients in pure YCOB (d_{12}=0.43 pm/V) and GdCOB (d_{12}=0.24 pm/V). However, there is no possibility to use x- or y-cut crystals as a type I noncritical second harmonic generators for Nd-groundstate lasers with wavelengths between 900nm and 950nm. Crystals of different compositional parameters x were grown and it was found that $Gd_{0.84}Y_{0.16}COB$ is able to convert the infrared radiation of Nd:$YAlO_3$ emitted from the groundstate transition (930nm) into blue light (465nm) at room temperature. Increasing the amount of Yttrium by one percent yields 1.4nm shorter phase-matching wavelengths. In a single pass experiment, the angle between the z-axis and the k-vector of the incident beam of a Ti:sapphire laser as the excitation source was varied and the angular acceptance bandwidth of $Gd_{0.84}Y_{0.16}COB$ was determined to be 29.7 mrad·cm$^{1/2}$ and 62.1 mrad·cm$^{1/2}$ for angle-tuning in the zx- and zy-plane, respectively. The temperature acceptance bandwidth was determined in a single pass experiment as well. The phase-matching wavelength shows a linear correlation with the temperature in the temperature range between 20 C and 140 C; $\partial\lambda/\partial T$ was determined to be 0.016 nm/K and the corresponding temperature acceptance bandwidth of $Gd_{0.84}Y_{0.16}COB$ is 42.8 K·cm.

4.4 B. H. T. Chai, plenary

Self frequency doubling in the Nd and Yb doped yttrium calcium oxyborate crystals

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Low cost compact visible laser source has a variety of applications, especially if the color spectrum matches the requirement for the displays. Among all the technology, semiconductor laser has the best chance to meet the need. Unfortunately, at present time, red laser is the only one reaching maturity. An alternative approach is to achieve the visible colors by two photon nonlinear or up conversion. Even though the nonlinear conversion technology is fully established, the overall cost is too high due to the high cost of individual components including laser diodes, laser and nonlinear crystals.

Self frequency doubling is a neat process by combining the laser and nonlinear crystal into one thus greatly simplifies the laser cavity design and assembly. However, since neither laser performance nor the nonlinear conversion efficiency are the best, we trade performance for the low cost. A recently discovered new congruently melting crystal, yttrium calcium oxyborate YCa4(BO3)3O, possesses such property. One advantage of this crystal is that high quality large single crystal can be produced by conventional melt pulling technique. The other one is the capability of high concentration of rare earth doping with less concentration quenching. Self frequency doubling was achieved with Nd doping. So far, we have obtained both green emission at 530 nm with the primary lasing wavelength at 1060 nm and red emission at 666 nm with the primary lasing wavelength at 1332 nm. However, we were unable to obtain the blue emission at 473 nm, since the gain cross section at 946 nm is simply too weak. We are now working one the scheme of self sum frequency mixing of 1060 nm with 810 nm pumping line. We will report of our progress of this work. Self frequency doubling was also achieved with Yb doping. However, because of the broad tuning range of the primary laser, the emission has multiple wavelengths. It is necessary to use a birefringence filter to achieve single wavelength lasing in order to get the stable frequency-doubled light.

4.5 M. Endo

Estimation of phase noise in a mode-locked tunable laser

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The tunable fiber lasers in the soliton regime are attractive ultrashort optical pulse sources. However, problems arise with tunable fiber lasers due to their susceptibility to mechanical and temperature fluctuations affecting the optical path length of the cavities. The resulting instabilities are the major barriers for their applications. The estimations of phase noise properties are important with respect to applications of the sources. We have demonstrated a passively mode-locked erbium-doped fiber (EDF) laser that is based on nonlinear polarization rotation to generate 60 nm tunable 270 fs pulses with 45 MHz repetition frequency at the center wavelength of 1558 nm. The wavelength tuning is accomplished by rotating a band-pass filter inserted into the resonator. We describe the estimation of phase noise in a tunable laser.
Noise mainly occurs from spontaneous emission of the gain medium and from fluctuations of the optical path length in the resonator. To maintain a stable condition, it is essential to reduce the influence of airflow and temperature fluctuations. The intensity fluctuation of the pump laser plays an important role in limiting the achievable noise reduction. The fluctuations in pump intensity changes the group velocity, the change

in the gain profile of the EDF, also changes its index profile. However, owing to the excited states of the gain medium having long relaxation times, the output pulses is not sensitive directly to the gain fluctuations except at low frequencies. Using an external feedback loop, the intensity fluctuations of the pump laser is stabilized. At the same time, the airflow and the temperature fluctuations in the resonator are closely controlled by using a double-sealed box with a temperature controller. A power spectrum technique is used to measure the noise relative to a radio frequency reference signal. Knowing the intensity and bandwidth of the pedestal, one can evaluate the noise of the laser. Amplitude noise has a contribution independent of the harmonic number. On the other hand, phase noise is associated with noise sidebands through its dependence on the square of the harmonic number. Timing jitter is a type of phase noise that can occur in a short time scale. We measured the noise spectral density sidebands at the 30th harmonic of the repetition frequency. The rms jitter over the frequency span of 30 Hz to 3 kHz is estimated to be below 47 parts in 106 of the round-trip time (1.0 ps) over a wavelength tuning range of 28 nm. The upper frequency limit is set by the noise floor of the spectrum analyzer for long relaxation times of the erbium ions. The lower frequency limit is imposed by the resolution bandwidth of the analyzer. Since phase noise of the laser is predominant at low frequencies, it should be possible to reduce the noise by actively controlling the optical path length of the resonator.

4.6 J. A. Fülöp

Improved two-pass second harmonic generation of femtosecond pulses

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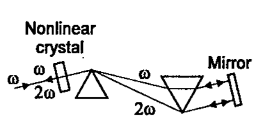

Fig. 1.

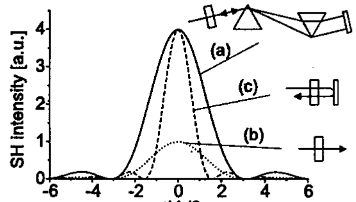

Fig. 2.

Two-pass arrangement [1] improved by a prism pair is proposed for increasing the efficiency of second harmonic generation (SHG) of femtosecond pulses (Fig. 1). The

dispersion of the phase difference between the two second harmonic (SH) fields, generated in a round-trip of the fundamental, is compensated in zero and first order by utilizing the dispersion of a prism pair. In the case of negligible second order dispersion, the proposed two-pass arrangement provides four times higher SH spectral intensity (Fig. 2, curve (a)) than the one-pass doubling (Fig. 2, curve (b)), in contrast to the uncompensated two-pass SHG, where only the SH peak power is increased fourfold, but the doubling bandwidth is halved (Fig. 2, curve (c)). Our calculations show that for pulses up to 45 fs, the uncompensated second order term in the dispersion of the phase difference can be neglected. For shorter pulses, this term leads to a significant broadening of the SH pulse.

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4.7 N. N. Ilichev

Continues wave operation of F_2 colour centres laser in LiF at 1.15 mm

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Tuning laser oscillation of F_2 colour centres in LiF in the region 1 - 1.26 mm [1] is interesting from the point of view of its practical application. Only quasy-continious wave laser action has been achieved up to now. Strong thermal lens in LiF prevents an obtaining cw generation. This fact was stated in early work [2].
Here we report our results on the first observation cw generation of F_2 colour centres in LiF at pumping by cw YAG:Nd laser. The LiF crystal was rotated. Moving of the crystal has solved the problem of heat removing from the pumping area in the LiF crystal. Output power 300 mW has been obtained at pumping power 9 W. Generation wavelength was close to 1.15 mm.

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4.8 L. Ivleva

Holographic recording and beam coupling in Barium Strontium Niobate single crystals doped with Cobalt

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Dynamic holographic recording in Sr0.61Ba0.39Nb2O6 single crystals doped with cobalt was investigated in visible region of spectrum. In two-wave mixing, the dependence of the gain coefficient on the grating period and the response time on the writing beam intensity were measured to calculate the Debye screening length, the diffusion length, the dark conductivity and the effective concentration of the carrier traps for the SBN:Co concentration series. The crystals are characterized by the high gain (=33cm^{-1}), the short response time (t=140ms at I=1W/cm^2) and the high photorefractive sensitivity (S=39cm^2/W). This material can be effectively used for dynamic phase grating recording with the low laser radiation intensity. Also, we present the results of recording of amplitude gratings in non-poled SBN:Co crystals. SBN:Co has a strong dichroism in linear and photoinduced absorption. The kinetic of photochromic grating formation was investigated and the differences from photorefractive effect were shown.

4.9 V. L. Kalashnikov

Automodulations in CW solid-state ultrashort lasers mode-locked by Kerr-lensing

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Last time, nonstationary regimes of ultrashort pulse generation in lasers, in particularly, in cw solid-state Kerr-lens mode-locked lasers, have gained a great deal of attention. Such regimes are of interest for investigators not only by themselves, but also from the point of view of pulse parameters control and generation of stable pulses with extremely short duration in stationary regime. The last is connected to the fact that the regions of laser parameters providing a stationary ultrashort pulse generation border with regions of nonstationarity and the knowledge of the features of nonstationary regimes and their relative positions in the laser parameters space will enable for directional tuning on desirable regime of generation. On the basis of a quasi-soliton parameters mapping in aberrationless approximation, we have studied numerically the autooscillations in Kerr-lens mode-locked solid-state laser. It was shown, that the ratio between self-phase modulation and self-amplitude modulation due to Kerr-lensing is a bifurcation parameter which determines stable, periodic, quasi-periodic or chaotic behavior in the system. Pulse stabilization is provided by two mechanisms: a negative feed-back for the chirped pulse at bandwidth-limiting element and Schrödinger soliton formation for nearly chirp-free pulse. However, the full chirp compensation by negative group-velocity dispersion causes the pulse destabilization. It was shown also, that the ultrashort pulse dynamics control may be efficiently performed by group-velocity dispersion variation, the pulse destabilization being accompanied by very interesting

from the point of view of applications regime of modulation of generation wavelength, observed experimentally. This modulation is caused by insertion of one of the compensating prisms from position corresponding to stable ultrashort pulse generation. To explain this effect, we accounted for the third-order group-velocity dispersion. Autooscillations, that our model predicts, qualitatively corroborate with experimental result.

4.10 V. L. Kalashnikov

Weak-nonlinear soliton in the solid-state laser with semiconductor saturable absorber

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Over the last years a great progress in the generation of extremely short laser pulses has been achieved. As the main mechanism of the pulse formation in the systems with semiconductor modulator the soliton mode-locking was proposed [1].
In this report we show, that the linear ac quantum-confined Stark effect in the semiconductor absorber forms a non-Schrödinger soliton in the presence of negative or positive group-velocity dispersion. It is known, that the near-resonance interaction of ultra-short pulse with excitonic resonance in quantum-confined semiconductor produces a shift of resonance, which is proportional to pulse amplitude a [2]. In this case the pulse experiences a self-phase modulation which is proportional to $|a|$ and the self-amplitude modulation which is proportional to $|a|^2$. We calculated the self-amplitude modulation coefficient to be 2.4 10^{-13} cm^2/W for Ti:sapphire laser with GaAs modulator. Calculations showed that for low pump power the pulse evolution is described by "weak-nonlinear" quadratic in field generalized Fisher's equation [3]:

$$\frac{\partial a(z,t)}{\partial z} = \left[\alpha - \gamma - l + (\alpha - \gamma + id)\frac{\partial^2}{\partial t^2} m\xi|a|\right] a \ ,$$

where z is the longitude coordinate, t is the local time, d is the dispersion coefficient, ξ is the Stark parameter, l is the unsaturable loss, α and γ is the gain and loss saturated by full pulse energy, respectively. "-" and "+" signs in Eq. correspond to blue and red shift of resonance, respectively. This equation has soliton solution in the form:

$$a(t) = a_0 ch^{-2-i\psi}\left(\frac{t}{t_p}\right) \ ,$$

where a_0 is the amplitude, ψ is the chirp, t_p is the pulse width. Note the power -2 for ch in the solution which makes the main difference from the soliton of "strong-nonlinear" (cubic in field) Schrödinger's equation. As was shown, the phase nonlinearity due to linear ac Stark effect allows to form the ultra-short pulse in the region of small negative for blue shift or positive for red shift dispersions. The factor of absorber-like action of linear ac Stark effect is connected to the "pushing out" of absorption line from the pulse

spectral profile. The soliton has essentially non-Schrödinger character due to non-zero chirp. Moreover the blue Stark shift substantially reduces the threshold of femtosecond generation in compare with soliton-mode-locking mechanism based on Schrödinger's soliton formation. On the other hand, the red shift increases the pulse duration for the smaller pump powers, that switches laser to the regime of the picosecond operation (so-called, picosecond collapse).

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4.11 A. V. Kir'yanov

Polarisation bistability in a Nd:YAG laser passively Q-switched with a Cr4+:YAG crystal under the weak resonant signal control

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Previously we reported the experimental observation [1] and theoretical simulation [2] of the drastic dependence of the state of polarisation of a neodymium laser passively Q-switched with a Cr4+:YAG crystal on relative orientations in the laser cavity of the passive switch and a partial polariser. It has been shown that operation of the laser is governed both by relative orientations of the Cr4+:YAG crystal (in other words, by orientations of Cr4+ phototropic centers with respect to the laser optical axis [3]) and of the intracavity polariser, as well as by the energy density of a giant pulse in the switch.

The aim of the present paper is to report results of novel theoretical simulations of a polarisation-bistable Nd:YAG laser passively Q-switched with a Cr4+:YAG crystal under the weak resonant signal control, in which 90° - flips of the giant pulse polarisation azimuth are observed. We show that such a polarisation-bistable device can operate as an all-optical transistor: One of the main parameters (polarisation) of the powerful neodymium laser can be controlled by the relatively weak signal delivered from a controlling CW laser or laser diode, wavelength of which falls into the Cr4+:YAG resonant absorption band. Polarisation characteristics of the device are determined by the self-induced nonlinear absorption anisotropy [4] arising in the switch due to interaction of intracavity powerful and extracavity weak radiations with Cr4+ phototropic centers.

Basing on the cavity polarisation eigenstate analysis and numerical solution to the rate equations describing the laser, we have analysed intensity dynamics, as well as

the dynamics of polarisation state in the conditions of "switched off" and "switched on" exterior weak resonant controlling radiation. We found the parameters' ranges for both the powerful and controlling lasers, when the most reliable and effective operation in the polarisation-bistable regime is expected.

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4.12 I. V. Klimov

Neodimium lasers, operating at different wavelength on $4F_{3/2} \leftrightarrow 4I_{13/2}$ transition in a number of crystal hosts

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Recently the possibility of the application of 1.44 μm Nd-laser instead of 2-μm Ho-laser has been demonstrated. This fact demanded the detailed investigation of the $4F_{3/2}$ $4I_{13/2}$ transition in Nd^{3+} ions.

In the paper the results of the study of the spectral and lasing characteristics of the $4F_{3/2}$ $4I_{13/2}$ transition in Nd^{3+} ions in a number of crystal hosts are presented. We analyze the conditions to achieve the efficient lasing at several wavelength corresponding to the transition between different Stark sublevels. The detailed analysis of the intracavity losses and their influence to the real efficiency of the pulsed Nd-lasers, operating at 1.44 μm are done.

We show the examples of the practical application of these lasers in medicine.

4.13 L. A. Kotomtseva

Multivalued steady states, switching regimes and nonlinear dynamics in a solid state laser with a saturable absorber

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Results of theoretical consideration of the steady states, their stability, switching regimes under change of the definite parameter and nonlinear dynamics of a single mode solid state laser with a saturable absorber (LSA) on the basis of model [1-2] are proposed.
There are two kinds of multivalued steady states due to action of nonlinear dispersion of both active and passive media when spectral width of an absorption line of absorber is more narrow than spectral width of the gain line of an active medium medium. Conditions for the coexistence of several such values of intensity and frequency, up to five, together with the zero intensity trivial state, are described analytically and their stability is considered in dependence on the parameters of an active medium, absorber and the cavity with attraction attention to the role of the detunings of the resonant frequencies of an active medium, absorber and cavity.
It appears that stability of the steady states is determined in great degree by the decay rates of populations of active and passive media. Conditions for the stabilization of the steady states with suppression of the relaxation pulsations during transient time are proposed. For the stable coexisting steady states switching regimes during adiabatic change of the pumping are demonstrated.
For the unstable steady states two types of regular pulsations at the different beginning conditions - some orders different in maximal values of intensity and periods of oscillations, can develop for the same parameters of a LSA. Possibility to control appearance of the definite type of such pulsations is demonstrated. Conditions for the experimental observation of described regimes of LSA operation are discussed.

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4.14 S. Kück

Investigation of Cr doped MgO and Sc_2O_3 as potential laser sources for the near infrared spectral range

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Cr^{3+} doped crystals are well investigated laser materials for the near infrared spectral range. They exhibit in low crystal field hosts broad band emission between 700nm and 1100nm. Although the obtained tuning ranges for the Cr^{3+} lasers are generally smaller

compared to Ti:Al_2O_3, they exhibit the advantage of diode pumping. During the last years, especially the colquirite crystals $LiCaAlF_6$, $LiSrAlF_6$, and $LiSrGaF_6$ were thoroughly studied and efficiencies up to 54% were realized. The major drawback of these crystals is the low heat conductivity resulting in small pump powers launchable onto these crystals. Therefore MgO and Sc_2O_3 seem to be interesting laser hosts for the Cr^{3+} ion, because of their high heat conductivities of $37\frac{W}{mK}$ (MgO) and $13.3\frac{W}{mK}$ (Sc_2O_3), viz. $31\frac{W}{mK}$ for Al_2O_3 (all data at 100°C).

Cr doped MgO exhibits the typical absorption and emission spectrum of octahedrally coordinated Cr^{3+}. Absorption bands are observed at 619nm ($^4A_2 \rightarrow {}^4T_2$), 452nm ($^4A_2 \rightarrow {}^4T_{1a}$), 283nm ($^4A_2 \rightarrow {}^4T_{1b}$), and 706nm ($^4A_2 \rightarrow {}^2E$). From these data the crystal field strength and the Racah parameters are determined to be Dq = 1615cm^{-1}, B = 586cm^{-1}, and C = 3249 cm^{-1}, thus Dq/B = 2.75 and C/B = 5.54. The emission covers the spectral region between 700nm and 1100nm. The room temperature lifetime of the Cr^{3+} ion in MgO is 30μs and single exponential. From these data, the peak emission cross section is estimated to be $\approx 4\times10^{-20}$ cm^2. Continuous wave laser oscillation at room temperature was realized for Cr^{3+}:MgO with output powers up to 50mW under argon ion laser pumping.

Cr doped Sc_2O_3 exhibits a rather unusual absorption spectrum. Typical bands of the octahedral Cr^{3+} at 670nm ($^4A_2 \rightarrow {}^4T_2$), 480nm ($^4A_2 \rightarrow {}^4T_{1a}$), 300nm ($^4A_2 \rightarrow {}^4T_{1b}$), and 710nm ($^4A_2 \rightarrow {}^2E$) are observed giving crystal field parameters of Dq = 1490cm^{-1}, B = 590cm^{-1}, and C = 3227 cm^{-1}, thus Dq/B = 2.53 and C/B = 5.47. In addition, a broad double structured band with peaks at 750nm and 910nm is observed. The origin of this band is unknown thus far. Two emission bands are observed between 700nm and 1100nm, corresponding to the octahedral Cr^{3+}, and between 1100nm and 1800nm.

In this contribution laser relevant spectroscopic data of Cr doped MgO and Sc_2O_3 will be presented and discussed in detail.

4.15 N. V. Kuleshov

Laser performance of diffusion-doped Cr^{2+}:ZnSe

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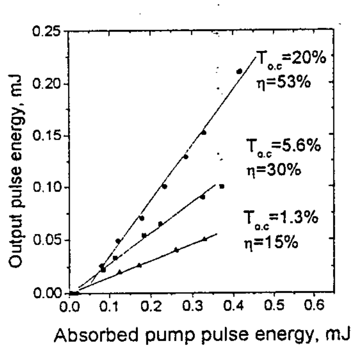
Cr^{2+}-doped ZnSe crystals are of great interest for development of tunable in spectral range of 2.1-2.7 μm solid-state lasers for applications in medicine (ophtalmology, neurosurgery, urology), optical communications, laser remote sensing of the atmosphere, and spectroscopy [1-2]. The laser active center in this material was identified as Cr^{2+} ion incorporated into the tetrahedral site. Peak stimulated emission cross section and lifetime of laser level for Cr^{2+}:ZnSe were estimated to be 8 x 10^{-19} cm^2 and 8 μs, respectively. The cw laser operation with Cr:ZnSe gave slope efficiency up to 63% using a cw diode-pumped Tm:YALO laser at 1.94 μm [3]. However, there is a problem concerned the high level of passive losses at the laser wavelength near 2.5 μm in samples of Cr:ZnSe with high chromium concentration required for development of compact diode pumped laser systems. In this paper Cr-doped ZnSe crystals of laser quality were prepared by a two stage process described in Ref.[4]. At the first stage, undoped single crystals of high optical quality were grown by a sublimation traveling heater method (STHM) without seeding. At the second stage, the ZnSe crystals were doped by the method of thermal diffusion from solid chromium films deposited upon the crystals of ZnSe. The passive losses of Cr:ZnSe crystals in the emission range near 2500 nm were measured to be less than 0.05 cm^{-1}. Peak absorption coefficients at 1.78 μm varied from 4 to 25 cm^{-1} for different samples in accordance with impurity concentration. The laser experiments were performed using 1.598 μm output of a Nd:YAG-laser-pumped $Ba(NO_3)_2$ Raman laser with pulse duration of 10 ns. A nearly hemispherical laser cavity was formed by a flat mirror with high reflectivity in the lasing region of 2.3-2.6 μm and by a concave output coupler with curvature radius of 150 mm and transmission of 1.3%, 5.6%, 12.6%, and 20% at laser wavelengths. The incident beam was focused upon the sample through the high reflecting mirror by a 32-cm focal-length lens. Input-output data for one of the best samples of Cr^{2+}:ZnSe ($\alpha_{1.78\mu m}$ = 23 cm^{-1}) using three output couplers are shown in Fig.1. The slope efficiency as high as 53% and laser threshold as low as 4 μJ with respect to absorbed pump energy were achieved. The round trip passive loss is estimated to be approximately 4%. The laser efficiency is expected to be enhanced by using pump wavelength around 1.8 μm peak of absorption band.



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4.16 W. H. Lowdermilk, plenary

NIF and the Path to Inertial Fusion Energy

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Construction of the National Ignition Facility (NIF) facility, which began in July, 1997, will be officially completed in September 2004. The 192 beams of NIFs multipass neodymium glass laser, each with 40x40-cm-aperture will be arranged in 24 modules, each in a four-high and two-wide array of 8 beams. The laser is designed to routinely deliver 1.8-MJ pulses at 350 nm wavelength, with peak power of 500 TW, shaped appropriately for ignition targets. These pulses will be delivered by a precise optical transport system through the final optics system on the 10-m-diameter, spherical aluminum target chamber. KDP crystals, used for harmonic generation, as well as all other final optics will be located in the target chamber. NIF also will use diffraction gratings on each beam to divert residual first harmonic and second harmonic light away from the target.
With the achievement of fusion ignition and energy gain of 10-20, expected to occur approximately in the year 2007, NIF will open the door to exploration of the scientific and economic feasibility of inertial fusion energy (IFE). Work has already begun at LLNL on advanced drivers that can produce the megajoule class pulses at repetition rates of 5-10 Hz and efficiencies above 5diode-pumped solid-state laser producing 100 J per pulse at a repetition rate of 10 Hz is under construction and will serve as a demonstration of this technology use in and IFE power plant. System design studies of a power plant with a 4 MW driver using this technology approach indicate the possibility of achieving cost-of-electricity by IFE that is competitive with other postulated advanced energy sources.

4.17 P. Maak

Acousto-optic Q-switching of an Er:YSGG Solid state laser

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Lasers emitting at optical wavelengths around 3 microns are of high practical interest in laser surgery, since water has high optical absorption in this wavelength region. The extent of the thermally damaged tissue can be restricted to a few micrometers when pulses shorter than a few microseconds (3-4 s) are involved [1].

One way to obtain high energy short pulses is Q-switching, which presents several difficulties in the case of such lasers. Passive Q-switch techniques were used, involving different materials, such as water, ethanol, InAs layers as saturable absorbers. Active Q-switching has been done by mechanical devices, such as rotating mirrors and prisms, electro-optic, acousto-optic devices and FTIR shutters. The obtained maximum output pulse energy values are of 50-100 mJ and minimum pulse duration values of 30-60 ns [1,3]. The maximum output pulse energy obtained with acousto-optic Q-switch was of 9.3 microJ, far below the values delivered by other techniques [2].

We investigated experimentally the acousto-optic Q-switching of an Er:Cr:YSGG laser emitting at 2.79 micron optical wavelength. We used a new deflection type TeO2 acousto-optic Q-switch with a maximum diffraction efficiency of 25operation of this type of Q-switch was demonstrated, obtaining maximum Q-switched pulse energy of 27 mJ, with pulse duration of 100-120 ns in single pulse, TEM 00 mode operation.

We have demonstrated that acousto-optical Q-switching of Er doped solid state lasers can result in comparable pulse energies and pulse durations as by other Q-switching methods. An optimization of the laser resonator and its operation has been made, by changing the output mirror reflectivity, resonator length, Q-switch position and Q-switching delay time. The optimisation led to the result, that in the case of the given laser crystal the optimum output-mirror reflectivity is of about 20switching delay time of 90-100 s.

Comparison of the free-running (with opened Q-switch) operation with the Q-switched mode at middle pump energy level provided a pulse energy ratio of 52value is the highest reported up to date to our knowledge.

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4.18 R. Menzel

New developments of phase conjugating mirrors based on stimulated Brillouin scattering

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Since many years phase conjugating mirrors (PCMs) based on stimulated Brillouin scattering (SBS) have been established as an effective tool to improve the beam quality of solid state lasers through compensation of pump-induced phase distortions in the active material. Usually two different laser setups were used, the master-oscillator-power-amplifier (MOPA), a high cost but also a very powerful system, which was realized with average output powers of more then 1 kW with near diffraction limited beam quality. Besides these very big systems PCMs can be used in single oscillators, the issue we made our special. By improving the resonator design the diffraction limited, average output power could be increased up to 50 W. This laser was realized with a flashlamp pumped Nd:YALO rod (7 mm x 150 mm). The SBS medium was SF6 at a pressure of 20 bar. In both setups MOPA and the SBS laser oscillator the properties of the SBS-mirror, substantially the high SBS-threshold, determine the possible output beam parameters. The SBS threshold is defined by the minimum laser light power, which is needed to reach 2 geometry in which the laser beam is focused into the SBS material exhibits peak power thresholds in the range of several 10 kW up to several 100 kW depending on the SBS material. The threshold can be reduced by the use of waveguide structures down to the range of 100 W as was demonstrated e.g. with multimode optical fibers. However these PCMs show a low reflectivity of 50 % and a small dynamic power range of 1:10. For solving these problems a novel phase conjugate mirror based on SBS in an internally tapered quartz fiber is presented. The basic concept of this mirror is the well known principle of a SBS-generator amplifier geometry, it combines a low SBS threshold and a large dynamic power range. With a passively Q-switched Nd:YAG laser with a pulse duration of 30 ns a peak power threshold of 500 W and an energy reflectivity above 93 % is demonstrated. To reduce the threshold well below the 100 W range new materials have to be used. Thus we use internally tapered capillaries filled with CS2. In a first experiment a peak power threshold of 25 W was measured. These low power threshold PCMs open the possibility of a new field of application improving the beam quality of diode laser bars by coherent coupling of the single emitters.

4.19 Y. Mori

Recent Development of New NLO Borate Crystals for UV Generation

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The interest in the use of borate crystals in ultraviolet (UV) nonlinear optics (NLO) has increased because all solid-state UV lasers obtained with NLO are in highly demand. Much effort has been spent on developing borates series, such as β-BaB_2O_4 (BBO) and LiB_3O_5 (LBO), in this decade. Recently another new borate crystals, $CsLiB_6O_{10}$ (CLBO) and $Gd_xY_{1-x}Ca_4O(BO_3)_3$ (Gd_xY_{1-x}COB) have been developed by the present author. Here, the growth, NLO and frequency conversion properties of CLBO and Gd_xY_{1-x}COB crystals are reviewed and their properties are discussed in relation to those of other nonlinear optical crystals, such as BBO and LBO.
CLBO showed the ease in growth and excellent NLO properties for 4th and 5th harmonics generation of Nd:YAG laser radiation. CLBO crystal with dimensions of 14 x 11 x 11 cm^3 could be grown by flux method for three weeks. Moderate birefringence makes CLBO possesse a smaller walk off angle to achieve better spatial overlapping of the mixing beams compared to BBO. Thus, higher conversion efficiency and better beam pattern of harmonics generation can be achieved. Its relatively large angular, spectral and temperature acceptance bandwidths have favored CLBO for stable 266 and 213 nm generation of high power Nd:YAG laser.
Gd_xY_{1-x}COB crystal is suitable NLO crystals for 2nd and 3rd harmonics generation of Nd:TAG laser radiation. These crystals also showed the ease in growth without cracks and bubbles by the Czochralski method. Gd_xY_{1-x}COB crystals had an uniformity of crystal composition along with growth direction so these crystals confirmed a substitutional solid solution of Gd_xY_{1-x}COB. For frequency conversion applications, it is important to use noncritical phase-matching (NCPM) condition along the principal axes due to the large angular acceptance and elimination of walk-off between fundamental and harmonics lights, leading to the higher efficiency. We have succeeded to generate NCPM THG and SHG of Nd:YAG laser (1064 nm) light in $Gd_{0.28}Y_{0.72}$COB. $Gd_{0.28}Y_{0.72}$COB possesses zero walk-off angle, and larger angular and temperature bandwidths compared to LBO. This means that $Gd_{0.28}Y_{0.72}$COB exhibits the better NLO properties compared to LBO.

4.20 V. Peters

Efficient laser operation of Yb^{3+}:Sc_2O_3 and spectroscopic characterization of Pr^{3+} in cubic sesquioxides

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The cubic sesquioxide Y_2O_3 (Yttria) is of great interest as a host material for rare earth dopants since the early sixties due to its high thermal conductivity. The isostructural Sc_2O_3 (Scandia) and Lu_2O_3 (Lutetia) exhibit as well as Yttria a very high thermal conductivity of $15.5\frac{W}{mK}$ (Scandia) and $12.2\frac{W}{mK}$ (Lutetia), measured at 50°C. Because of their high melting points of around 2500°C it was not possible in the past to grow those sesquioxides with good optical quality from crucibles. Since 1996 attempts are beeing made at our institute to grow the high melting oxides from rhenium crucibles with the Czochralski-, Nacken-Kyropoulos-, and lately the Bridgman-method. First samples of good optical quality have been obtained.
Especially Scandia exhibits a rather strong crystal field, when doped with rare earth ions. The resulting large Stark-splitting is considered to be helpfull for quasi-four-level systems such as Ytterbium-lasers. An $Yb(\approx 6.5\cdot 10^{20}cm^{-3})$:$Sc_2O_3$ doped crystal showed efficient laser operation, when pumped with a Titanium-Sapphire laser at 941nm. A maxiumum output power of 970mW at 1041nm was obtained with approximately 1.85W of incident pump power.
Furthermore Yttria and Lutetia show effective phonon energies around $430cm^{-1}$, which is very small for oxide crystals. Since low phonon energies are usually favourable for upconversion processes Praseodymium was also chosen as a dopant ion to investigate the upconversion behaviour. However, no emission from the ^3P_j-levels could be detected even at low temperatures, regardless of the excitation wavelength. All fluorescence can be assigned to transitions from the $^1D_2$-level. A possible reason for the complete absence of emission from the ^3P_j-levels could be an autoionisation process to the conduction band of the host crystal. Photoconductivity measurements that allow the determination of the energetic positioning of the Pr^{3+}-ion within the bandgap will be presented.

4.21 A. V. Podlipensky

4.22 I. T. Sorokina

Compact diode-pumped continuous-wave Cr:YAG laser

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The Cr^{4+}:YAG laser, first reported in [1], is an attractive broad-band laser source, operating in the 1.5 micron region. Due to the relatively high threshold it has been traditionally pumped by medium-frame neodymium lasers.

The reported [2] diode-pumped operation of related to Cr^{4+}:YAG Cr^{4+}:forsterite and Cr^{4+}:Ca_2GeO_4 required the ideal beam of the rather complex and expensive master-oscillator-power-amplifier (MOPA) source [2] or Yb-fiber laser [3].

Very recently we reported the first, to our knowledge, direct diode-pumping of Cr^{4+}-doped YAG with conventional diode arrays at room-temperature. The laser output achieved 80 mW in continuous-wave regime [4].

The remarkable feature of this laser is the simplicity and compactness of the resonator, being a standard 3-mirror end-pumped cavity consisting of only two collimated diodes, an active medium, a curved mirror, a dichroic input mirror and an output coupler. Recently, by adding the third diode and optimization of the cavity- and pump-mode volume we obtained 180 mW of output power at room temperature, and 200 mW at 1°C. The tuning was accomplished over more than 120 nm, limited mainly by the optics.

In this paper, we present the details of these latest laser results along with the results of the study of the influence of excited state absorption at the lasing wavelength using *in-situ* measurement method, as well as of the adverse effects of interionic interaction between chromium ions in different crystallographic sites and different valencies.

Summarizing, we believe Cr:YAG laser to be a promising candidate for compact real-world tunable eye-safe sources of 1.5 micron radiation.

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4.23 R. Szipocs

Multi-color, mode-locked Ti:sapphire laser with zero pulse jitter

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Broadly tunable cw, picosecond and femtosecond laser systems such as Ti:sapphire (Ti:S) lasers [1] play an important role in cw and time resolved spectroscopy. The recent advent of chirped mirrors [1,2] (CM) allows now for broadband feedback and ideal dispersion control in such lasers, resulting in sub-10-fs laser operations in mirror-dispersion controlled [3] and in hybrid prism pair / chirped mirror controlled Ti:S oscillators. In our recent publication we proposed [1] that the application of fused silica prism-pairs in combination with dispersion matched CM-s would allow for the construction of high output power, broadband Ti:S oscillators comprising relatively long, highly doped laser crystals. A variety of applications in ultrafast spectroscopy (e.g. pump-probe or non-degenerate four-wave mixing experiments [4]) require synchronized two- (or multi-) wavelength femtosecond pulse laser operation.
In this paper we propose a novel laser setup for two- (or multi-) color, synchronized pulsed laser operation. It is achieved by the proper design and installation of Brewster-angled output couplers in a broad spectrum, Kerr-lens mode-locked Ti:S laser. The output couplers exhibit narrow reflectance bands at different wavelengths but when combined they result in uniform spectral transmittance. The intracavity dispersion is optimized by combining a fused silica prism pair with CM-s. The 4 mm long Ti:S crystal is pumped at 3.5 W from a Millenia laser. The spectra of the two laser outputs are separated by some 17 nm in accordance with the reflectance charateristics of the OC-s. Both outputs had 52 nm spectral bandwidth with pulse durations around 25 fs. Because of the inherent property of the setup, the time jitter of the two outputs is zero. Its easy handling and simple setup can make this laser a usefull device in multi-wavelength ultrafast spectroscopy.

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4.24 P. Tosin (M. Kehrli)

Manufacture of Fibers with Multiple Claddings

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The construction of novel types of fiber lasers often requires doped fibers which first have to be designed, manufacturbd and finally characterized. In this presentation we give a comprehensive survey of the development of novel doped multiple clad fibers. Starting with a design of the refractive index profile of such a fiber, we have optimized the manufacturing based on an MCVD (modified chemical vapor deposition) process. Tests of the manufactured fiber including the measurements of the absorption spectrum and the dopant concentration are reported.

4.25 H. P. Weber

High-power diode-pumped solid-state lasers

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Multimode output powers of diodepumped solid-state lasers in the range of several hund-red Watts will soon be commercially available. Strong thermal effects in the active material reduce however the useful output power range and lead to varying beam quality. Apart from catastro-phic fracture of the active material, thermal lensing and birefringence show the most disturbing influence on the laser performance. Although requiring quite complicated setups birefringence reduction schemes were demonstrated successfully in the past. However, compensation of the phase front distortions resulting from the temperature dependence of the refractive index (dn/dt-term) and the expansion of the material (end-effect) is not solved yet. Sophisticated resonator designs involving several amplifyer elements and/or variable curvature mirrors are possible means to reduce the influence of the thermal lensing. Another possibility is to take benefit of the effect itself by using a heated optical element as compensating element. The end effect as well as the dn/dT-part has the potential to be used in a compensating element. For high-power lasers, transversal pumping, especially of Nd:YAG rods, is preferred. In this case a compensating element with a negative dn/dT, which is placed inside the resonator, seems to be promising. This scheme has the potential to completely correct phase front distortions. Optical glasses are available with a negative dn/dT, whose absolute value is about the same as the one of YAG. Arrangements for practical realization are proposed. Detailed analysis was performed using the analytical approach for thermal lensing effects assu-ming homogeneously heated laser rods

and compensating elements. Taking material constants from literature it is shown that just about 1% of absorption is necessary to fully passively compensate the thermal lens in the laser rod. By choosing the appro-pri-ate geometry of the compensating element, a temperature increase of about 70 K and a maximum tensile stress of about 50 MPa is expected. For these values, a single rod Nd:YAG was assumed at a pump power of 2kW and an output power of about 650 W. Such a compensating element significantly increases the stability range of a given reso-nator. Selecting the appropriate resonator geometry it is even possible to maintain al-most constant beam parameters over almost the whole pump power range.

4.26 K. Yoshida

Optical Properties and Diode Pumped Operation of High-Performance Nd Doped YAG Ceramics for Solid-State Lasers

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Recently, polycrystalline $Nd^{3}+$:YAG ceramics with high optical quality has been developed. The synthesis of highly transparent YAG ceramics is technically very difficult because optical materials for a solid-state laser must meet extremely severe requirements. Polycrystalline, transparent Nd : YAG ceramics were fabricated by a solid-state reaction method using high-purity Nd2O3, Al2O3, and Y2O3 powders. In this paper, some physical and optical properties of polycrystalline YAG sintered at 1800 °C ceramics were compared with YAG single crystal fabricated by the Czochralski method. The laser oscillation of highly Nd3+ doped YAG ceramics was shown.

5 Laser methods in medicine

5.1 E. Bálint, poster

Flow cyclometric analysis of cell membrane events induced by interferon-alpha

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Laser-based flow cytometer permits promt experimental monitoring of fluctuations in the molecular status of cell surface membranes and in effect can "report" the occurrence of early signal transduction events of interferons. The interferons are important regulatory molecules, capable of affecting a number of cell functions in addition to the much studied proliferation of variety of cell types, inhibition of viral replication and growth. Clinically there is increasing importance of anticancer and antiviral activity of interferon-alpha (IFN). The IFN acts primarily by interaction with membrane receptors during signal transduction. The aim of this study was to pursue the importance of the cell membrane changes in the signal transduction of IFN from the receptor binding to the biological effect.

Membrane potential of human cells was quantitated by flow cytometry using a voltage-sensitive oxonol dye. The relationship of plasma membrane biophysical properties to expression of IFN effects was investigated on different types of model cells (lymphocytes, U937 monocytes, Daudi lymphoblast and K562). Our studies have suggested changes in the plasma membrane environment after IFN treatment, including changes in the ion flux, membrane potential, alteration of microviscosity, etc. These changes in the membrane properties depend on the IFN sensitivity of cells. We obtained information from the early steps of signal transduction of IFN from measurements of the effects of different microfilament-, ionflux-, differentiation-effective agents on the membrane potential. Connection was found between the immunregulatory system and the neurotransmitters effecting the modulation of natural killer cells cytotoxicity.

5.2 T. V. Chichuk, poster

Biophysics bases of low intensive laser irradiation action on leucocytes

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The leucocytes were irradiated without and in whitness of ekzogenic (phthalocyanine) and endogenic (porphyrins) photosensitizers. Concentration of photosensitizers in plasma was determined by fluorimetric method. We investigated the influence of He-Ne ((= 632.8 nm) laser irradiation (LI) on a functional activity human's and rat's leucocytes. For this was used the method of luminol-dependent chemiluminescence with zymozan-stimulation of the phagocytes. It was found out that laser irradiation initiate a priming of the leucocytes, which reveal itself after zymozan-stimulation of the phagocytes. Leucocytes,s functional activity was changed after laser irradiation and depend on dose irradiation and concentration of photosensitizers in cells and in plasma.

Known that calcium ions play the important role in the leucocytes,s priming. We have studied change to calcium concentration in cell cytoplasm after laser irradiation. For this was used fluorimetric method with Fura-2AM. It was found out that laser irradiation initiate a change basal level calcium in the leucocytes,s cytoplasm. These process depend how from dose irradiate, so and from concentration of the photosensitizers.

Hereon we investigated the laser-induced photosensitized lipid oxidation of leucocytes membranes. These process depend how from dose irradiate, so and from concentration of the photosensitizers also. Probably exactly lipid oxidation initiated the entry of calcium in cells.

Due to got results is formulated hypothesis about mechanism of action low intensive laser irradiation on a human blood leucocytes.

5.3 T. V. Chichuk, poster

Action of Russian photosensitizers: Photohem and Photosense upon blood

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Effects of the Photodynamic Therapy (PDT) on the blood of 25 patients with oncology diseases (Basal-cell carcinoma, squamous-cell carcinoma, T-cell lymphoma) were investigated. The PDT was implemented in the presence of domestic photosensitizers (PHS): Photohem (hematoporphyrine derivative, HPD) and Photosense (sulfonated aluminium phtalocyanine, AlPc). Change of different parameters of the patients' blood after intravenous administration of PHS and implementation of PDT was measured. Concentration of PHS in plasma was determined by fluorimetric method. The system "hemoglobin-hydroperoxyd-luminol" and method of plasma inhibition of accumulation of TBA-active products of yolk lipoprotein peroxidation (TBA - thiobarbituric acid) were used for determination of blood plasma antioxidative activity (AOA). Accumulation of TBA-active products in the blood lipoproteins and plasma was investigated with fluorimetric and spectrofluorimetric methods. Functional activity of human blood leukocytes was registered by the method of luminol depended chemiluminescence.
It was discovered, that the contents of Photosence in the blood plasma of different patients in a month after administration constituted from 12% to 60% and the one of Photohem from 9% to 31% of the level of PHS after 24 hours of administration.
Increase of functional activity of blood leukocytes of most patients was registered on the day after administration of PHS. After two weeks was observed a decrease of chemiluminescence activity of cells.
The accumulation of TBA-active products in the blood lipoproteins and plasma took place after intravenous administration of PHS and implementation of PDT. Increase of accumulation of TBA-active products after PDT continued for 1-2 weeks with following decrease.
?? of the blood plasma was changing for 4 weeks after administration of PTS and implementation of PDT To investigate the dynamics of these parameters is important for elaboration of means to diminish side effects of PDT. For example increase of skin photosensibility due to PDT treatment can cause burns and erythema. Increase of the phagocyte activity and initiation of lipid peroxidation cause development of erythema reaction. Knowing dynamics of these parameters one can substantiate some measures of prophylactics.

5.4 D. Chorvat

Interaction of merocyanine 540 with biological membranes

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The binding of lipophilic photosensitizer dye merocyanine (MC) 540 was reported to be limited to the cell plasma membrane, unable to traverse it in intact cells. In our work, we have been investigated the localisation of merocyanine 540 molecule in lipidic bilayer by means of time-resolved laser spectroscopy, using iterative deconvolution method for fluorescence lifetime distribution analysis. In contrast to monoexponential fluorescence decay in solution, time resolved fluorescence of MC-540 bound into a membrane can be successfully fitted by biexponential decay. Higher complexity of biological membranes reflects in widening of its lifetime distribution. According to the reference lifetime data set taken in various solvents, we have attempt to localise the position of merocyanine chromophore in the lipid bilayer. Due to charged SO3-group, merocyanine 540 easily create dimers. Being highly photoreactive, the MC 540 also easily undercome an isomerization upon irradiation. Both processes are strongly solvent dependent. Therefore, we have carried out several quantum chemistry calculations in order to explain some aspects of its molecular structure and dynamics in various conditions. It was shown that irradiation of MC 540 with white light provoked a generation of singlet oxygen [e.g. Hoebke 88] that, because of its high reactivity and short life span, reacts primarily with targets close to its site of production. Unsaturated lipids were proposed to be likely targets. We have confirmed the presence of excessive cell photodamage after strong irradiation of MC 540, and we have been investigating several intracellular fluorescence indicators during the process of MC 540 phototoxic influence in human lymphocytes isolated from healthy subjects.

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5.5 B. Eppich

Optical phase measurements on biological cells

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The imaging of morphological and physiological states of cellular and sub-cellular objects gains increasing importance in bioanalytics. Recent experiments have shown that the distribution of the phase shift a monochromatic optical wave experiences passing through a cell is closely related to the morphology as well as to the current metabolic activity of the cell. Since measurements of phase shift distributions can be performed without any cell damage, as it usually happens due to staining and/or long-term preparation processes, and have the potential of being carried out time-resolved, they may open a new window for the observation of dynamic intercellular metabolic processes. This article presents phase measurements on different cell types using a laser phase microscope and correlates the results with the metabolic state of the cells. Furthermore, a new approach for phase measurements will be introduced. This approach is based on the tomographic reconstruction of the Wigner distribution

function of the beam passing the cell and can be realized by a very simple setup. Besides, it may allow for time-resolved measurements.

5.6 I. E. Ferincz

Age and intended correction dependence of effective ablation rate during photorefractive keratectomy

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Nowadays, the photorefractive keratectomy (PRK) is widely used technique to correct near-sightedness and astigmatic errors of the eye. The results of PRK treatments mainly depend on the effective ablation rate. The effective ablation rate is calculated from the difference of the intended and achieved correction. Wound healing, corneal dehydration, postoperative treatment, patient's age, and intended correction all can effect the effective ablation rate. To increase the accuracy of the outcome of the laser treatment we have analyzed our results for correlation between patient's age, intended correction and the effective ablation rate. We have performed 613 PRK treatments with an ArF excimer laser system to correct near-sightedness. We have selected 311 (173 patients, 81 male, 92 female) case where the follow-up was at least 6 months long. The age of patients were in the range of 18 years to 56 years (mean: 30.2 +/- 7.01 year). The intended corrections were between -1.0 D and -9.0 D for myopia (mean: -4.52 +/- 2.13 D), and the diameter of the ablation zone was 5.5 mm or 6 mm. By analyzing the results we have found that the effective ablation rate depends on the patient's age and the intended correction. The numeric value of the ablation rate in nm/pulse unit is given by the following expression if the fluence of the ablating beam is 160 mJ/cm^2:

$$197 + 0.53A - 3.16C\ ,$$

where A is the patient's age in years, and C is the intended correction in diopters. In case of older patients (A > 40) and large intended correction (C < -5 D) the PRK treatment can lead overcorrection. By using the presented equation the accuracy of the PRK treatments can increase, thus avoiding the overcorrection.

5.7 M. Frenz

'Tissue characterization by optoacoustic wave detection

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The generation of acoustic waves by irradiating tissue with short laser pulses has implications in medical therapy and diagnostics. The therapeutic effects of optoacoustic waves range from stresswave-induced tissue ablation to undesired mechanical damage during pulsed laser treatment. In the field of tissue diagnostics, optoacoustic waves are used to obtain information about tissue optical properties and for the imaging of tissue structure. Optoacoustical signals were generated by irradiating absorbing targets with nanosecond laser pulses at various wavelengths. As light source we used optical parametric oscillators (OPO) with a pulse duration of 5 ns and an overall tuning range from 400 to 3600 nm wavelength with a linewidth of about 1 nm in the visual range and less than 30 nm in the infrared range. The laser induced stress transients were measured with an optical transducer. The transducer is based on changes of reflectance of a glass-water (perfluorocarbon liquid) boundary during passage of a pressure wave. The fast variations of reflectance are probed with a continuous HeNe laser that is focused onto the interface. The small elliptical detector spot with principal diameters of approximately 150 and 300 m is imaged with a lens onto the active area of a fast photodiode. A high sensitivity for the detector is achieved by using an incident angle slightly smaller than the critical angle of total internal reflection. In addition, a wide probe laser beam and a time-gated CCD camera were used for two-dimensional pressure wave detection. Measurements in transmission mode and reflection mode (transducer and incident OPO pulse are at opposite sides or at the same side of the sample, respectively) were compared. In reflection mode an infrared-transparent liquid (perfluorocarbon liquid) was used to uncouple acoustical and thermal effects. The effective attenuation coefficient of target samples was determined by an exponential fit to the pressure signal. Cartilage and water absorptions were compared between 1860 nm and 1935 nm wavelength. For bone optoacoustical signals were measured between 1835 nm and 1935 nm. Optoacoustic measurements with an infrared OPO give the possibility to obtain optical properties of tissues over a wide wavelength range. Especially in reflection mode in vivo tissue characterization and medical diagnostics are possible. Two-dimensional pressure wave detection was used to visualize the acoustic field generated by irradiating absorbing targets of various shapes with OPO pulses. This technique can be used for the analysis of absolute pressure values and for imaging of buried absorbers in tissue.

5.8 T. Juhász

APPLICATIONS OF FEMTOSECOND LASERS IN CORNEAL SURGERY

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ABSTRACT

We investigated potential applications of ultrashort pulsed laser technology in refractive corneal surgery in animal studies. Ultrashort pulsed lasers operating in the femtosecond time regime are associated with significantly smaller and deterministic threshold energies for photodisruption, as well as reduced shock waves and smaller cavitation bubbles than the nanosecond or picosecond lasers.

Our reliable all-solid-state laser system was specifically designed for real world medical applications. Contiguous tissue cutting was achieved by scanning the 5 μm focus spot of the laser below the corneal surface. Typically pulse energies in the order of a few μJ were used in the experiments which are markedly smaller than that used with picosecond or nanosecond laser pulses.

Combination of different scanning patterns enabled us to perform corneal flap cutting, femtosecond laser keratomileusis, and femtosecond intrastromal vision correction in enucleated porcine, rabbit, and primate eyes. Intrastromal cuts proved to be highly precise and possessed superior dissection and surface quality. Preliminary in vivo animal studies with femtosecond intrastromal vision correction indicate that consistent refractive changes can be obtained with the method. We conclude that femtosecond laser technology is capable to perform a variety of corneal refractive procedures with high precision, offering advantages over current mechanical and laser devices and enabling entirely new approaches for refractive surgery.

The correction of the corneal refractive power obtained as a result of the surgery is compared with predictions based on the analytically solvable shell model of the cornea as well as with the results of the numerical simulations utilizing the finite element analysis.

5.9 G. Klebanov

Molecular and cell mechanisms of laser therapy.

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Low-level laser irradiation (LLLI) is widely used for treatment most inflammatory diseases. However the mechanisms of positive therapeutic action of LLLI in the red and infrared regions of spectrum are not fully understood.

In our previous works we proposed hypothesis devoted to molecular and cell mechanisms of laser therapy. It includes several postulates:

1. Endogenous porphyrins absorb light in red area of the spectrum and well known as photosensitizers. The target of laser action may be blood cells in particular leukocytes and blood lipoproteins, which contain porphyrins.
2. Porphyrin-dependent free radical photoinduced reactions lead to lipid peroxidation in leukocyte membranes. Accumulation of lipid peroxidative products, for example, lipid peroxides, in cell membranes couses increase ion permeability, mainly for Ca2+ - ions.
3. Increased of Ca2+ ion concentration in leukocyte cytoplasm induce different Ca2+ - dependent events leading to cell priming. In the priming state the cell may be produce biological active compounds (active oxygen species, hypochlorite anions, nitric oxide and so on) more than in the rest state. Some of them have bactericidal properties, for example, hypochlorite anions. It was found that nitric oxide, promoter of EDRF (Endothelium Derivated Relaxity Factor) induce vasodilatation and enhancement of blood microcirculation
4. Increased citokines production accompany leukocyte priming. On other hand, citokines may stimulate cell proliferation and formation the new vessels. It may be useful from medical standpoint. The laser-dependent processes leading to enhancement of blood microcirculation is of prime importance during ischemic-reperfusion events

There is experimental evidence of main postulates for our hypothesis in this report.

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5.10 T. P. Kraposhina, poster

Laser therapy of squamous cell hyperplasia of vulva

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The absence of rather effective measures incidence of therapy of Squamous cell hyperplasia (SCH) of vulva, the high level of recurrence even after destructive methods of treatment demand more effective methods of treatment.
44 patients at the age of 35 to 58 suffered SCH of vulva from 4 to 12 years were examined and treated. The area of the lesion was from 150 to 195 mm^2, consisted of spots and had a pruritus. To confirm and specify the diagnosis we used vulvoscopical, cytological and histological methods if needed.
Laser therapy was applied with a help of the compact laser set with copper vapour laser "BIM-1" generating two waves 510,6 nm and 578,2 nm working in impuls-periodical regime and having the power 3 W. Patients were exposed to "spot by spot" method of treatment twice a week with the power density 1 W/cm2 and treatment exposure of 30 sec per spot 0,7-0,8 cm in diameter. The total number of procedures is 9-10.
From the 3d procedure of laser therapy we noticed the beginning of the degeneration of lesions and pruritus decrease. The pruritus disappeared to 5-7 procedure. Till this period the full degeneration of SCH centres happened with changing to constant stratified squamous epithelium. Every patient had such a result. Further observation during 2,5-3 years showed the absence of recurrence. Thus, copper vapour laser therapy is a highly effective, pathogenetically settled down measure of local therapy of squamous cell hyperplasia of vulva.

5.11 J. Lademann

Laser spectroscopic investigation of the stability of coated titanium microparticles used in sunscreens

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Chemical UV-A and UV-B- filters and coated titanium dioxide microparticles are the effective components realizing the protective abilities of commercial sunscreen products. The spectral absorption, the penetration behavior and the stability are basic properties characterizing these filter substances. While the qualitative and quantitative analysis of the penetration process of sunscreen components into the skin is measured by tape stripping in combination with spectroscopic measurements [1,2] no suitable methods are available to investigate the mechanical stability of the microparticles. X-ray fluorescence measurements need a long and expensive preparation procedure of the samples. These measurements are carried out under vacuum condition so that the properties of the samples can be changed during the analyses.
The aim of the following investigations was to analyze the mechanical stability of the coating material by measuring the titanium/aluminium concentration ratio during the manufacturing and penetration process by laser spectroscopic measurements.
The investigations were carried out using commercial coated titanium dioxide particles in emulsion. The coating material contains aluminum compounds. The Ti/Al ratio determined by laser induced plasma spectroscopic measurements was used for the characterization of the mechanical stability of the coated titanium dioxide particles. A pulsed laser beam was focused on the samples achieving power densities of 10^9 up to 10^{12} W/cm^2, high enough to produce a plasma with temperatures of several thousand degrees. By this way small quantities of the material were evaporated and split into high-excited basic compounds that can be detected by fluorescence measurements. The laser beam was scanned over the sample surface to analyze the space distribution of the Ti/Al concentration ratio on the sample surface.
The determined Ti/Al ratio was identical for the investigated sunscreen samples, i. e. for the basic material, for the sunscreen and for the sunscreen amounts fixed on the human skin. Instabilities of the coating could not be detected, when the sunscreen components were handled under conditions relevant in practice. A small change in the Ti/Al ratio was observed, when in a centrifuge extreme share forces were applied to the sunscreen samples demonstrating that the used method reflects instabilities of the coating.

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5.12 N. L. Larionova, poster

Scattering of laser light wave on spherical particles of lens biotissue

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The investigations of the problem of laser light (l 630 nm) scattering by spherical particles in case of plane wave was performed on the base of a complete general solution of the problem of interactive electromagnetic scattering by clusters of arbitrary configured nonidentical spheres [1]. It is the general case of the Mie theory, that research the electromagnetic scattering by a single sphere. Besides the scattering of a Gaussian beam by the Mie scatter centers using Bromwich formalism was investigated [2]. The optical model of the lens tissue was presented by a system of spherical particles spaced at distances on the order of their diameter, the latter was more less then radiation wavelength. The number of particles was being varied from one to several tens. The spatial distribution of scatterers was taken in a definite order near to cubic lattice. Also the calculations were performed for systems of particles which coordinates were specifically realized in random fashion according to the specified probabilities defined by the approximation of hard spheres [3] and by the medical knowledge about features of texture of deseased and healthy, old and young human eye lenses [4-6]. The influence of orientation of the system of particles with respect to the scattering plane and that of the spacing between its particles on the LSM elements were investigated. For small particles an analytical expression amenable for calculation was gained by averaging of the coordinates in the approximation of excluded volume which allows for the LSM to be calculated with different scatterers concentrations. As a result of modeling for some particular realization of coordinates and dimensions we gained the image of a speckle structure of scattered radiation followed by analyzing its contrast and characteristic dimensions as a function of its optical constants. The last were varied in a range of values corresponding to the normal and pathological lens. The modeling results are compared with the previously reported experimental data [7].

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5.13 V. B. Loschenov

The methods of laser induced fluorescence spectroscopy of tissue in vivo for diagnostics and therapy control

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The main principle of biomedical applications of tissue spectral analysis include the following areas:

1. Tumor diagnostic due to the fluorescent properties of endogenous porphyrins accumulated in malignant tissues.
2. The evaluation of photosensitizer (PS) and other drug concentration for both diagnostic and therapy control applications. For example it is necessary to control the photosensitizer concentration and its chemical state to implement the appropriate tactics of photodynamic therapy (PDT) procedure.
3. The evaluation of oxygen saturation and hemoglobin concentration in microcircular and arterial blood vessels of tissue including the mucous of intracavital organs.

The main advantage of spectral analysis of tissues in vivo is its noninvasivity. This allows one to get information about tissue condition without affecting dynamic of various biological processes. Such interference may be undesirable or even dangerous. For example the taking of biopsy probe of melanoma may result in to the dramatic generalization of tumor process. Another advantage of optical tissue analysis is the possibility to process data in real time and to control parameters of therapy process according to information acquired. For example the in situ analysis of photosensitizer concentration and its chemical state during photodynamic therapy makes it possible to correct the laser irradiation intensity (the photobleaching of photosensitizer requires the decrease in laser intensity or stop laser irradiation for some time). It is also necessary to mention that due to the enormous progress in the field of opto-electronics and microprocessor technique the system for spectral analysis of tissues in vivo can be relatively small so that to be portable. Our clinical system for optical biopsy is based on a PC board fiber optics spectrometer. Laser light is delivered by flexible fiber probe to the tissue. The distal end of the fiber probe is designed so that it could be inserted into the biopsy channel of serial endoscope for investigation of intracavital organs or could be inserted into the needle for investigating of deep tissue layers. The fluorescent and the scattered laser light enters the receiving fibers which surround the delivering one and passed to the spectrograph. The signal is digitized, passed to the computer, processed and displayed. The autofluorescent measurements of patients with stomach cancer, lung cancer and thyroid gland were done. The spectral differences between normal and malignant tissues were found out. To enhance the contrast between normal and malignant tissues we also applied the exogenous PS - ALA and sulphanated aluminum phthalocyanine. The great contrast was observed in stomach tumors sensitized with ALA induced protoporphirin IX (PPIX) The control of photosensitiser concentration in patients undergoing PDT were done. It was shown that PS fluorescence is decreased during laser irradiation due to photobleaching. The grate bleaching rate is observed for ALA induced PPIX. The laser induced fluorescence spectroscopy method is a promising tool for versatile medical applications in diagnostics and therapy.

5.14 I. B. Manuchin, poster

Laser therapy of condyloma acuminata of vulva

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Human papilloma virus (HPV) infection (one of the most wide-spread sexually transmitted diseases. A special feature of the disease is the tendency of progress with forming of immunosuppressive condition and high level of recurrence. Till nowadays there is no etiotropical measures of treatment of HPV infection. There were 42 patients with HPV vulvitis, who were tested in different methods including vulvoscopy, cytology and investigation of microbiocenosis of vagina. In every case numerous condyloma acuminata without atypia were discovered. After the etiotropical therapy of vaginitis and normalization of microbiocenosis of vagina the laser therapy was starting. Laser therapy was applied was held with copper vapour laser "BIM-1" generating two waves 510,6 nm and 578,2 nm and working in impuls-periodical regime with output power 3 W.

Patients were exposed to "spot by spot" method of treatment twice a week with the power density 1-1,5 W/cm2 and treatment exposure of 25 sec per spot 0,5-0,6 cm in diameter. From the third procedure of laser therapy there was the beginning of dry necrosis of condylomas. The full degeneration of the lesions was noticed after 9-10 procedures. The further observation showed , that in 36 (85,7%) cases a remission of the disease during 3 years, 6 (14,3%) had the recurrent in 7-8 months. Therefore copper vapour laser therapy is an effective, nontraumatic, painless method of treatment condyloma acuminata, which let us achieve strong revision of the disease.

5.15 G. N. Minkina, poster

CO2 laser in the treatment of the wide-spread condylomatosis of cervix uteri

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Laser vaporisation is the preferable method of treatment condylomatosis of cervix uteri as it is the best for extensive condylomatosis, stretched forms and multicentrical located and located far from the centre.

Laser vaporisation with the help of "Limmer" laser set (Germany) was made for 283 patients with histological diagnosis of condyloma of cervix uteri. The average effect of one procedure is 55% and was in the opposite proportion of the area of the lesion (till 25% ectocervix) is only 8%. With 50% of sick ectocervix - 23% already. And it leads only to a small improvement when total lesion of cervix uteri with passing to fornix vaginal. In cases of wide-spread condylomatosis demand repetitions of destruction, specially careful in vaginal rugae. In this it is better to start the vaporisation from the external border of the lesion, because the epithelium regeneration starting from the periphery of the wound and if some lesions stay here, their proliferation will lead to a failure. The effect of laser vaporisation of the wide-spread condylomatosis with 2-stage treatment is 52% and rise very much with the immunotherapy.

5.16 E. A. Mironova, poster

Laser and nonlaser effects on bioelectrical plant activity

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External stimuli induce fast changes of bioelecrtric potentials and these changes are the main form of the information exchange in plants. Earlier such electrophysiological measurements were hold on the separate large plant cells or cells series by the microelectrode technique. We measured bioelectrical responses (BERs) of entire plants (3-week old cucumber sprouts Cucumis sativus L.) induced by low-energy local laser and nonlaser stimuli by the macroelectrode technique on the 33 wavelengths in the UV, visible and IR ranges. Influence was given by creation of light spot (diameter 5 mm) on the upper plant leaf under presence of background illumination. Potential changes were measured on the plant stem. Dependences of BERs amplitude from the incident light intensity and spectrum of light action (AS) on the plant in the wavelengths range 330-3390 nm are presented. AS is normalized to the incident intensity 0.6 mW/cm2. We measured absorption and transmittance spectra of the cucumber leaf and compared them with the AS. Plant reaction to the stimuli of visible spectral region is connected with the cells activity in this diapason due to photosynthesis: SA in the visible range have maximums coincided with photosynthesis maximums. It well corresponds with noted data given by microelectrode technique. BERs in the range 720-850 nm are probably connected with phytochrome light sensitivity. BERs were measured in IR-region 1100-3390 nm as well. This fact maybe conditioned by photosyntesing cells activity increasing induced by light absorption by water. Without background illumination plant BERs to the IR-stimuli were absent. The research was supported by Russian Foundation for Basic Research, grant no. 96-15-97782 (Scientific Schools of Russia).

5.17 G. Müller

Laser Optics in Medical Diagnostics and Therapy

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The application of optical process technologies in biological tissue requires a specific understanding of light propagation in strongly scattering media. New measuring technologies and computer-aided simulation methods have brought about a breakthrough. In this paper methods for quantitative determination of the optical constants a (absorption coefficient), s (scattering coefficient) and the phase function, characterized by the so-called g-factor, are demonstrated and related therapy methods, such as laser-induced thermal therapy, methods of antirheumatism diagnostics and laser doppler blood flow determination, explained. In addition to light propagation in clouded media, non-linear optical processes, such as photoablative methods in laser angioplasty and in laser lithotripsy, too, have gained in importance in medical therapy and diagnosis.

5.18 V. A. Orlov

The study of motility of individual microparticles by phase sensitive laser spectroscopy

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The results of a study of motility of micron- and submicron-sized particles by precession light scattering spectroscopy are presented. The weak scattering sensitivity of the developed technique is at least one order higher in contrast with known scattering light analysis-based techniques for detection and study of microparticle dynamic characteristics. High resolution of the setup used < 0.01 Hz allows to measure infra low velocities V<<1 micrometer per second, diffusion characteristics of scattering particles and also to record peculiarities of their motility. This is connected with special use of lasers, optical schema of setup and technique of signal processing. Earlier the motility study of some species of microorganism having flagellum type of motility has been made using the spectrometer [1, 2]. The unknown before details of microorganism motility were found. The application of special mathematical processing of photoelectrical signals in digital form allows to separate their phase variations from amplitude variations and to measure displacement of Brownian particle in probe volume. Such approach considerably extends the capabilities of technique used for study of particle dynamics in liquid since it allows to analyze both determined component of individual microobject displacement and fluctuations connected with Brownian motion.

[1] Bagayev. S.N., Gusev, V.A., Orlov, V.A., Panov, S.V. Study of Dynamic Peculiarities of Motility of Some Species of Microorganisms by Quasi-Elastic Light Scattering. Proceedings of SPIE, 1998, v. 3251, pp. 267-272.

[2] S.N.Bagayev, V.A.Gusev, V.A.Orlov, S.V.Panov. The observation of dynamic peculiarities of motility of individual bacterium cells. Laser Physics, 1998, vol.8, N3, pp.803-808

5.19 P. G. Pleshanov, poster

Chemical specification of heavy metals from radioactive contaminated soils in Russia and lung tissues of Chernobyl clean-up workers

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The primary objective of this work was to combine the characterization tools such as laser mass spectroscopy and optical spectroscopy with synchrotron radiation based techniques such as X-ray absorption spectroscopy (XAS), X-ray fluorescence microprobe (XFM), EXAFS spectroscopy for the study of heavy metal contamination in the Tula district of Russia that was contaminated by one of the major plums of Chernobyl. Also the second effort was the characterization of heavy metal contaminants from the fluids extracted from the lungs of Chernobyl victims using novel lavage techniques and in lung tissue samples obtained from clean-up workers and autopsies of Russian radiochemistry industry workers who died of cancer or lung disease.
The results showed that the heavy metal environment in these samples is complex and may vary from site to site but that XAS can provide useful information about the species present, even at law concentrations and in complex structural environments. The site to site variation shown for Zn, Zr, in particular, demonstrated that detailed information must be obtained for each site in order to understand the potential biological hazard associated with given elements.

5.20 A. V. Priezzhev

Laser diagnostics of pathologies by measuring structural and dynamic parameters of biological fluids

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Recent success in the study of interaction of laser radiation with biological tissues in general and with biological fluids in particular, serve as a basis for the development of new optical techniques for noninvasive and/or early diagnosis of many wide-spread diseases and for monitoring of a patient's state. This is of utmost importance in relation to diabetes, oncology, cardio-vascular and autoimmune diseases, etc. In the case of diabetes the current research is aimed at raising the sensitivity of noninvasive (in vivo) measurements of glucose content in blood. In this direction considerable success is achieved with polarimetry, Raman spectroscopy, multi-wavelength absorption/reflection spectroscopy. Nonspecific early diagnostics of cancer is efficiently performed via the analysis of static and dynamic light scattering from blood plasma samples in vitro. In comparison with biochemical tests for specific diagnostics the optical technique is much cheaper and faster and better suits for screening of risk groups of population. Static light scattering from whole blood samples in vitro can be efficiently applied for the quantitative measurement of aggregation properties of red blood cells. The latter exhibit dramatic changes in case of many diseases like cardio-vascular, autoimmune, diabetes, etc., and are related to severe aggravations in the state of a patient as hemorheological disorders. Recent developments in the design of compact laser Doppler blood flowmeters and microscopes and of laser capillaroscopes enable highly accurate dynamic measurements of blood microcirculation that are highly important for quantitative estimates of hemorheological disorders, tumor grows and destruction, etc.

The paper will provide an overview of the state-of-the-art of the research in these directions and will discuss trends for future developments.

5.21 A. M. Sergeev

Recent Developments in Optical Coherence Tomography

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Recent progress in optical coherence tomography (OCT)is surveyed including concept development, new technological findings, and clinical applications. Fundamentals of probing objects in turbid media by short coherence radiation are discussed with a projection on biotissue imaging. A modern approach to the implementation of OCT technology is presented and new clinical modalities based on this approach are demonstrated such as endoscopic, laparoscopic, and dental OCT.

5.22 E. Sobol

Time-resolved, light scattering measurements of cartilage and cornea denaturation due to FEL radiation

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Cartilage and cornea are glycopolymer and protein based systems with native macromolecular structure that is of great importance for their functional properties. The alteration of macromolecular structure changes the number and size of light-scattering centers in the tissue. In this paper, light scattering is used to monitor the dynamics and energy thresholds of laser-induced structural alterations in biopolymers due to irradiation by a free electron laser (FEL) in the infrared (IR) wavelength range 2.2-8.5 m. Attenuated total reflectance (ATR) FTIR spectroscopy was used to examine infrared tissue absorption spectra before and after irradiation. Light-scattering by bovine and porcine cartilage and cornea samples was measured in real-time during FEL irradiation using a 630-nm diode laser and a diode array with time resolution of 10 ms. The data on the time dependence of light scattering in the tissue were modeled to determine initial points and kinetic coefficients for denaturation as functions of wavelength and laser fluence. We found that denaturation threshold is slightly lower for cornea than for cartilage, and both depend on laser wavelength. An inverse correlation between denaturation thresholds and the absorption spectrum of the tissue is observed for many wavelengths; however, for wavelengths near 3 and 6 m the denaturation threshold does not exhibit the inverse correlation, instead being governed by heating kinetics of tissue. ATR spectra of 2.4 mm thick cartilage samples were measured before and after irradiation at 6.0 and 2.2 m. At 6.0 m, where the absorption is relatively high, the spectrum of the FEL irradiated (front) surface showed changes, while the spectrum of the back surface was unchanged. This difference results from pyrolysis at the front surface due to laser-induced overheating of the outer surface. For 2.2 m irradiation, where the absorption is relatively small, the spectra of the front and back surfaces of the irradiated sample were unchanged, although light scattering shows that denaturation had begun on the front surface. This indicates that the smaller absorption provides more uniform heating of tissue without pyrolysis resulting in measurable alteration of tissue structure. Thus, we have shown that light scattering is useful for measuring denaturation thresholds and dynamics for biotissues except where the initial absorptivity is very high.

5.23 A. Soundoukov, poster

The new approach to the treatment of adults from toxic diphteria

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The diphtheria was expanded and captured almost all Russian regions at the end of 80-th years. This disease has got character of epidemic. Heavy current of illness, the often complications and high lethality have forced to search for the new approaches to treatment. The aim of this work is to estimate clinically the efficiency of laser irradiation of blood at heavy forms of diphtheria. New method of treatment efficiency evaluation is applied in the case of diphtheria. The course of treatment included 5-8 procedures of laser invasive irradiation for 1 hour per day. Low-intensity He-Ne (633 nm) laser was used for these procedures. The treatment of 109 patients showed that the quantity of specific complications and lethality were essentially reduced. The new diagnostic method of intracavity laser refractometry allowed to monitor the illness level and to determine the dose of irradiation objectively.

5.24 R. Steiner

Laser Doppler sensor for laser assisted injection

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Superficial and endoscopic injection of expensive drug solutions of exactly controlled volume need a sensor guided injection system to find the right path into the veins. To combine the sensor technology and a laser assisted channel forming device with the endoscope, all information and the radiation of the power laser (Ho:YAG) must pass through a single fiber. The doppler effect proved to be an appropriate method for sensing the blood flow in the veins even in deeper tissue layers. Comparison with ultrasound shows that ultrasound does not meet the requirements for such a system. Strong efforts have been undertaken to eliminate distortions of the Doppler signal. The results demonstrate the practicability of this device.

5.25 E. F. Stranadko

Research and recent achievements in laser photodynamic therapy

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Our research is aimed to enhance the PDT technique and widen the borders of its application in malignant tumors and non-oncologic diseases. Development of photodynamic therapy (PDT) sufficiently widened the possibilities of modern oncology. PDT is efficient not only in initial stages of primary superficial malignant tumors, but also in multiple tumors and in visceral locations (cancer of lung, esophagus, stomach). PDT is being successfully applied to locally spread tumors for recanalization of hollow organ (obturative cancer of esophagus, cardia, rectum). PDT is effective in tumor recurrences after traditional treatment (cancer of skin, tongue, oral mucous, breast) and in intradermal metastases of breast cancer and melanoma. Assessment of 308 patients treated in the State Research Center for Laser Medicine with PDT showed overall therapeutic effect in 94in 55 Russia second-generation photosensitizer of chlorin e6 derivative group - photoditazine (n-methylglucosamine complex of chlorin e6) - had been completed and a limited series of clinical trials had been performed. The preparation showed high selectivity of accumulation in tumoral tissue (contrast coefficient T/N = 15), photodynamic activity, high absorption of energy at 664 nm, rapid clearance from the organism. These properties of photoditazine allow to solve the main problem of the first-generation photosensitizers - long-term skin phototoxicity, and reduce treatment period from several days to 2 - 3 hours. Clinical trials revealed high therapeutic efficacy of photoditazine in skin cancer, melanoma, cancer of larynx, esophagus, oral cavity, vulva. Recently a new multitask laser device "Metalas-M" has been tested and approved by the Committee for New Technique of Russian Ministry of Public Health. This laser is suitable for plastic surgery, cosmetics as well as for PDT with most photosensitizers. We have undertaken experimental studies on lethal photosensitization of microorganisms, most frequently met in chronic suppurative wounds and trophic ulcers, with Gramm-positive and Gramm-negative bacteria (staphylococcus aureus, proteus mirabilis, pseudomonas aeruginosa). Clinical use of PDT with incoherent light after topical application of photosense in 40 patients with chronic suppurative wounds and trophic ulcers led to clearing of wound surface in 1 day and formation of granulation tissue in 3 - 4 days.

5.26 H. van den Bergh

Photodynamic therapy of age related macular degeneration pharmacokinetics and therapeutic results

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Results will be presented on the clinical and preclinical optimization of this therapy using different dyes. It will be shown how quasi-quantitative fluorescence angiography is used in the optimization of this multiparameter study. Short term leakage and blood flow will be correlated with long term visual acuity. Details of some of the apparatus specifically designed for this study will be presented.

5.27 V. A. Volnukhin

Low-intensive laser therapy of patients with granuloma annulare and its effect on microcirculation in the skin and blood lipid peroxidation.

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Granuloma annulare (GA) is a chronic dermatosis, characterized by necrobiotic dermal papules which often assume an annular configuration. Vasculitis is one of the main suspected mechanisms of GA's pathogenesis. We have studied the therapeutic efficacy of low-intensive laser irradiation of patients with GA and its influence on microcirculation in the skin and blood lipid peroxidation. Laser exposes were administrat by two methods: by means of transcutaneous irradiation of the blood (0,633 μm) or by the way of local irradiation of the granuluma annulare lessions (0,89 μm). A positive clinical effect has been achieved in 84,7% patients, significant therapeutic effect - in 69,3 % (remission - in 30,8%, considerable improvement - in 38,5%). Blood microcirculation distorbs have been determined in the lesions of patients before the treatment, characterized by amplification of the basal blood flux level and amplitude of the vasomotions and decrease of the microvessel reactivity; it has been found the decrease of the antioxidant activity in plasma and circulated erythrocytes. Both the first and the second method of the low-intensive laser therapy accompanied by the passing of the clinical symptomatics has lead to the normalisation of microcirculation in the skin and blood lipid peroxidation.

6 Symposium

6.1 K. Midorikawa

Efficient Phase-Matched High-Order-Harmonic Generation by Guided Femtosecond Ti:Sapphire Laser Pulses

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We have demonstrated the phase-matched high-order-harmonic generation of femtosecond Ti:sapphire laser pulses with two different guiding methods. Generation efficiency of the high-order harmonic was improved by phase-matched propagation in the guiding channel. More than 100-fold enhancement around the 25th harmonic (32 nm) was obtained with a 3-cm-long, Ar-filled hollow fiber. The harmonics around the 49th harmonic (16 nm) were also enhanced by two orders of magnitude compared to those in the plateau with a 7-mm-long, self-guided pulse in Ne. High-harmonic conversion efficiency of 10-6 was obtained by phase-matched propagation in Ne, producing ¿ nJ harmonics in the cutoff region around the 49th harmonic. In both experiments, the harmonics near the cutoff region were preferentially enhanced. The results are well explained by considering both the intrinsic phase based on the single-atom response and the macroscopic phase matching in the high-intensity interaction region. The flat intensity profile achieved in the guided structure is considered to clearly manifest the intrinsic phase behavior of the harmonics. Tunability of the harmonics and possibility of further increase of generation efficiency are also discussed.